BMT Fluid Mechanics

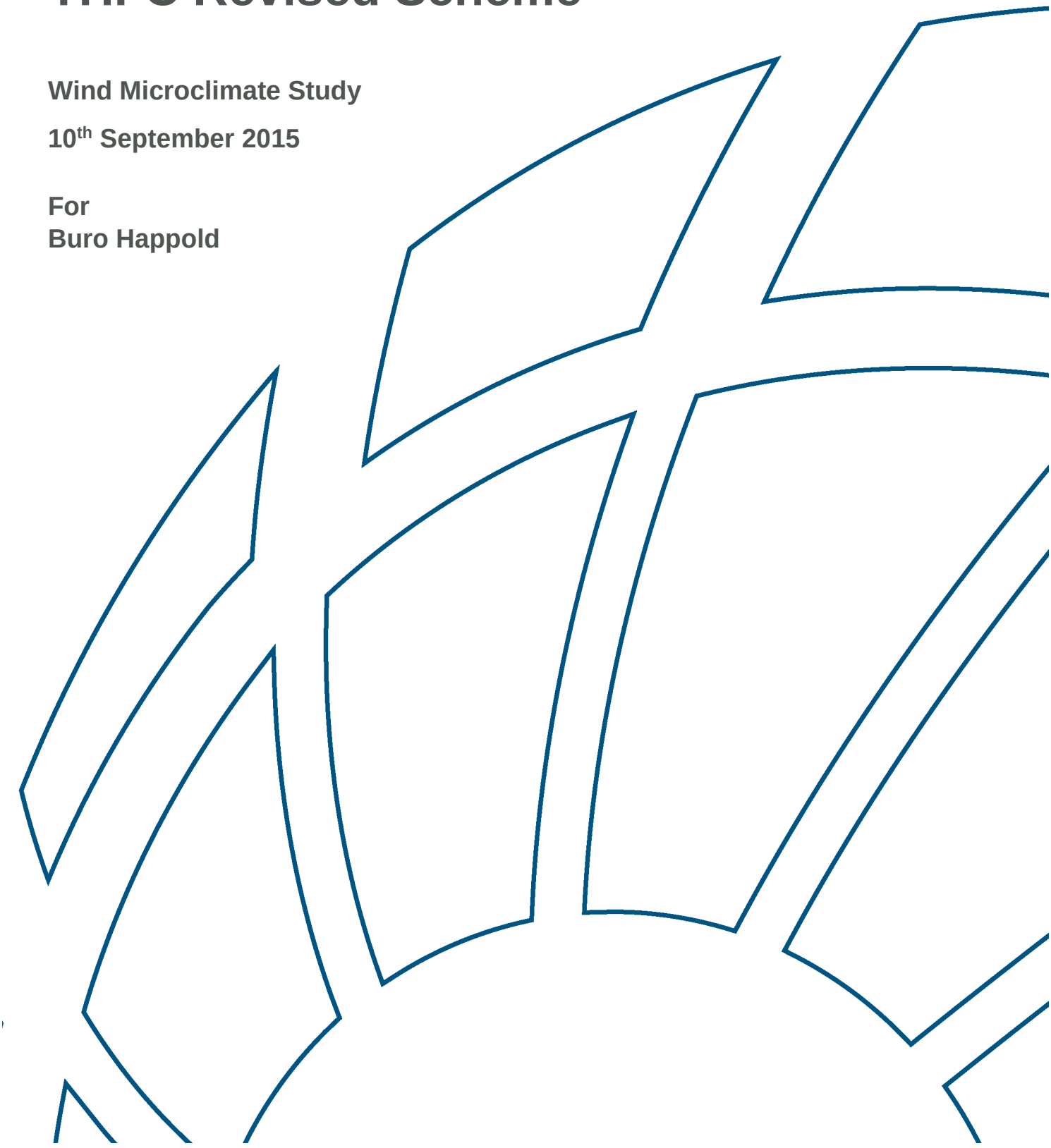
Project No. 431660

THFC Revised Scheme

Wind Microclimate Study

10th September 2015

For
Buro Happold



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THFC Revised Scheme Wind Microclimate Study

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EXECUTIVE SUMMARY

Background

A boundary layer wind tunnel study has been carried out by BMT Fluid Mechanics Ltd. (BMT) to assess the wind microclimate for the proposed THFC development in London, UK.

The boundary layer wind tunnel study has enabled the pedestrian level wind environment at the site to be quantified and classified in terms of suitability for planned usage, based on the industry standard Lawson criteria for pedestrian comfort and safety.

The study combines measured pedestrian level wind speeds at key areas in and around the site with long-term wind frequency statistics to determine the probability of local wind speeds exceeding comfort and safety thresholds for a range of common pedestrian activities based on the industry standard Lawson criteria. This defines the type of activities for which the wind conditions would be safe and comfortable.

Conclusions

The boundary layer wind tunnel study has assessed the wind microclimate for the proposed development. On the basis of the wind tunnel modelling, the following conclusions have been drawn:

- In the absence of soft landscaping and wind mitigation measures, pedestrian wind conditions are generally considered suitable in terms of pedestrian comfort and/or safety for planned activities. However, several exceptions to this occur both in terms of pedestrian safety and comfort.
- With the introduction of proposed landscaping and wind mitigation, all locations in and around the site are considered suitable in terms of pedestrian safety, throughout the year and for all phases of construction.
- While the majority of locations are considered comfortable for the intended use with the introduction of proposed landscaping and wind mitigation, there are some areas that remain unsuitable in terms of pedestrian comfort during the various construction stages and for the completed masterplan

Mitigation measures that would be expected to address the remaining unwelcome wind conditions for the completed masterplan have been identified. It is recommended that the effectiveness of these solutions be verified via wind tunnel testing at an appropriate stage of the design process.

THFC Revised Scheme Wind Microclimate Study

1. Introduction

This report summarises the results of a boundary layer wind tunnel study, commissioned by Buro Happold, to assess the wind environment for the proposed THFC development in London, UK.

The boundary layer wind tunnel study has enabled the pedestrian level wind environment at the site to be quantified and classified in terms of suitability for planned usage, based on the industry standard Lawson criteria for pedestrian comfort and safety.

The following configurations were tested:

- The proposed stadium within existing surrounds, with proposed shop, first storey of the health centre and opening day podium, referred to as the 'opening day scenario'
- The opening day scenario with mitigation
- The proposed stadium within existing surrounds, with proposed shop, completed health centre and completed podium with mitigation, referred to as the 'completed podium'
- The proposed stadium within existing surrounds, with proposed shop and hotel with mitigation, referred to as the 'completed hotel'
- The proposed stadium within existing surrounds, with proposed shop, hotel and sport development with mitigation, referred to as 'completed sports development'
- The proposed stadium within existing surrounds, with proposed shop, hotel, sport and residential developments, referred to as the 'completed masterplan'
- The completed masterplan with mitigation

2. The Assessment of Wind Microclimate

The UK Met Office defines a microclimate as the distinctive climate of a small-scale area. The weather variables in a microclimate, such as wind, may be different to the conditions prevailing over the area as a whole.

Wind microclimate assessments consider the wind conditions that would result upon the introduction of a new development into an existing space.

Such assessments predict the proportion of time an area will experience wind speeds in excess of threshold values for safety and stability and threshold values associated with a series of typical activities such as walking, awaiting a bus or sitting within a café, restaurant or bar outlet. It can therefore be shown within the various parts of a new development proposal and the neighbouring properties, whether wind conditions are suitable or unsuitable, and whether or not design adjustment or mitigation measures are required. It is for this purpose that wind microclimate assessments are undertaken.

The industry standard criteria for such assessments are commonly referred to as the Lawson criteria and emerged during a period of substantial research by eminent wind engineers of the time, many of whom individually presented proposals for criteria within wind engineering literature, including Davenport[1] in 1972. Lawson himself presented what has become the 'University of Bristol' variant of the Lawson criteria in 1973[2], prior to a collaborative initiative that produced the London Docklands Development Corporation (LDDC) variant of the Lawson criteria[3].

The LDDC variant of the Lawson criteria applies a single percentage probability of exceedance of a range of wind speeds, and associates different wind speeds to different types of usage. This offers a relatively simple and practical manner for the assessment of wind comfort and safety. It is this approach that BMT adopts.

3. Study Area

3.1. Site Location & Surrounding Area

The proposed development site is located in London, UK. The site is bounded by Northumberland Park Street to the North, Worcester Avenue to the East, Park Lane to the South and High Road to the West.

At present the area immediately surrounding the proposed development principally comprises low to medium rise commercial and residential buildings.

The site location is presented within the context of the wider surrounding area in Figure 3.1. Figure 3.2 presents a plan view of the proposed development.

One configuration of the surrounding area is considered in the current study, namely, existing surrounds.

3.2. Proposed Development

The proposed development is an approximately 50m high stadium which is elliptical in plan. It is situated on a 7m high podium. The podium area to the south of the stadium also contains part of the larger development, featuring the Tottenham Hotspur shop, a hotel, sports and residential developments. The podium area to the North of the Stadium includes the community health centre. The current study considers the stadium with the later developments staged over several phases.

3.3. Soft Landscaping

The wind environment has been assessed for the proposed development with current soft landscaping proposals.

3.3.1. Opening Day Scenario

For the opening day scenario, the soft landscaping modelled comprised the following:

- Planter, ~0.5m tall, with ~0.5m hedging and 9 x ~10m trees in South-East area of podium
- Planter, ~0.5m tall with 2 x ~10m trees in South-East area of podium
- 2x planter, ~1m tall, with ~0.5m hedging in North-East area of podium
- 2x planter, ~1m tall, with 3x 2.4m trees in North-East area of podium

As illustrated graphically within Figure 3.3a.

3.3.2. Construction Phases

For the construction phases, additional soft landscaping was modelled comprising the following:

- Stepped planters, approximately ~1m tall on the southern podium with trees ~10m tall.

As illustrated graphically within Figure 3.3b.

3.3.3. Completed Masterplan

For the completed masterplan, the soft landscaping modelled comprised the following:

- Trees (~5m tall) around the residential area and the sport development
- Trees (~10m tall) around the proposed development

As illustrated graphically within Figure 3.3c.

3.4. Wind Mitigation Measures

The wind environment has been assessed for the proposed development with and without wind mitigation schemes. The wind mitigation measures were developed in conjunction with Populous and Allies and Morrison, the architects for the scheme, during an interactive workshop session to alleviate unwelcome winds.

3.4.1. Opening Day & Construction Phases

For the opening day scenario and subsequent construction phases, the proposed wind mitigation measures comprise the following:

- Screen, with a porosity of approximately 50%, and being approximately 2m tall x 1m wide located either side of the entrances along the southern and northern façade of the stadium
- Solid wall (being approximately 4m tall x 2m wide) located at the western entrance to the stadium
- Solid signs (being approximately 2m wide x 6m tall) suspended 3m above the podium from the SE façade of the stadium.
- Site hoarding (being approximately 2m high) around construction areas

The wind mitigation measures are included within Figure 3.4a.

3.4.2. Completed Masterplan

For the completed masterplan, the proposed wind mitigation measures comprise the following:

- Tree (~1.8m tall) on the North-West corner of the South-East residential tower
- Hedge (~1m tall) along the North of the sport development
- Hedges (~1.6m tall) around the tops of the atriums, at the base of and on the roof terraces of residential developments and on the podium of the sport development
- Parapets (~1.6m tall) on roof terraces of residential developments
- Parapets (~1.2m tall) on podium of sport development
- Screen, with a porosity of approximately 50%, and being approximately 2m tall x 1m wide along the southern façade of the stadium
- Solid wall (being 4m tall x 2m wide) located at the western entrance to the stadium

The wind mitigation measures are included within Figure 3.4b.

4. Assessment Methodology

4.1. Boundary Layer Wind Tunnel Studies

The assessment of environmental wind flows in the built environment lies outside the scope of internationally recognised wind codes, which focus on wind loading issues. In addition, there are no handbooks or engineering methods from which reliable assessments of the complex environmental wind flows that shape the pedestrian level wind conditions can be derived and numerical / computational methods such as computational fluid dynamics do not readily apply to turbulent wind flows in the built environment.

As a result, a purposely-designed boundary layer wind tunnel study was used to provide a reliable quantification of the pedestrian level wind environment within the following key areas:

- Pedestrian access routes
- Entrances
- Recreational areas, including roof terraces

The study combines wind speed-up factors at key areas in and around the site with long-term wind frequency statistics to determine the probability of local wind speeds exceeding comfort and safety thresholds for a range of common pedestrian activities. The threshold wind speeds are based on the industry standard Lawson criteria. The wind speed-ups are measured in the model-scale boundary layer wind tunnel testing for a full range of wind directions. The wind statistics are transposed from the nearest suitable weather centre to apply directly at the site.

4.2. Wind Climate Analysis

Details of the annual and seasonal climate wind analysis relevant to the site are presented in Appendix A.

4.3. Wind Tunnel and Model Details

Details of the model scale and construction, along with photos of the model and wind tunnel setup are presented in Appendix B.

The model scale of 1:200 is large enough to allow a good representation of the details that are likely to affect the local and overall wind flows at full scale. In addition, this scale enables a good simulation of the turbulence properties of the wind to be achieved.

4.4. Measurement and Analysis

The technical details relating to the instrumentation, measurements and analysis for the wind environment study along with the assessment criteria to which they are compared (Lawson criteria) are described in Appendix C.

The Lawson criteria define the type of activities for which the wind conditions would be safe and comfortable. An area that has relatively low wind speeds and would be comfortable for recreational use (involving standing or sitting) would also be suitable for uses that tolerate higher wind speeds such as walking.

The wind environment was assessed at a total of 99 locations for the proposed development. Details of proposed pedestrian activities, assumed in the assessment, are also provided in Appendix C.

Measurements were taken for a full range of wind directions in increments of 22.5°.

4.5. Wind Direction

The 0° wind direction has been chosen to coincide with the OS Grid north (90° east, 180° south, 270° west). The wind direction denotes the direction, which the wind is blowing *from*.

5. Results

5.1. General

Results are provided for the following configurations:

- The proposed stadium within existing surrounds, with proposed shop, first storey of the health centre and opening day podium, referred to as the 'opening day scenario'
- The opening day scenario with mitigation
- The proposed stadium within existing surrounds, with proposed shop, completed health centre and completed podium with mitigation, referred to as the 'completed podium'
- The proposed stadium within existing surrounds, with proposed shop and hotel with mitigation, referred to as the 'completed hotel'
- The proposed stadium within existing surrounds, with proposed shop, hotel and sport development with mitigation, referred to as 'completed sports development'
- The proposed stadium within existing surrounds, with proposed shop, hotel, sport and residential developments, referred to as the 'completed masterplan'
- The completed masterplan with mitigation

5.2. Wind Speed-Up Factors

The measured wind speeds are converted into wind speed-up factors. These are defined as the ratio between the measured wind speeds at a height of 1.5m above the ground and the wind speed at the reference height of 50m.

5.3. Threshold Wind Speed Exceedance

Wind speed-up factors are processed in conjunction with wind statistics for the site to derive exceedances of threshold wind speeds relevant to comfort and safety criteria.

5.4. Annual and Seasonal Assessments

The results of the wind speed measurements are summarised in graphical format in Appendix D, in terms of comfort and safety ratings derived for each pedestrian level measurement location.

6. Assessment

6.1. Approach to Assessment

6.1.1. Safety

At each area investigated, the suitability of the pedestrian level wind environment in terms of safety is assessed based on the Lawson criteria for pedestrian safety (see Appendix C). Safety is determined for the 'able-bodied' and for the 'general public'. For the general public a wind speed of 15 metres-per-second occurring once per year is rated as unsafe, with the potential to de-stabilise the less able members of the public including the elderly, cyclists and children. Able-bodied users are more likely to be capable of defending themselves against extreme pedestrian level winds and thus experience distress at a higher threshold wind speed of 20 metres-per-second, once per year.

6.1.2. Comfort

At each area investigated, the suitability of the pedestrian level wind environment in terms of comfort for various activities is assessed based on the Lawson criteria for pedestrian comfort (see Appendix C). The assessment takes full account of seasonal variations in wind conditions and pedestrian activities. For example, conditions for recreational activities focus on summer, but also consider spring and autumn, whilst conditions for pedestrian thoroughfare, access or waiting (example bus stops) consider all seasons, with winter usually being the critical season. The activities considered, and their relation to the Lawson comfort criteria, are summarised as follows:

Suitability		Lawson Comfort Criteria
Outdoor seating	For long periods of sitting such as for an outdoor café / bar, a private balcony	'Long-term sitting' in Summer
Entrances, waiting areas, shop fronts	For pedestrian ingress / egress at a building entrance / shop front, window shopping, or short periods of sitting or standing such as at a bus stop, taxi rank, meeting point, etc.	'Short-term standing / sitting' in all seasons
Recreational spaces	For outdoor leisure uses such as a park, children's play area, etc.	'Short-term standing / sitting' from Spring to Autumn
Leisure Thoroughfare / Strolling	For access to and passage through the development and surrounding area	'Leisure Thoroughfare /

Suitability		Lawson Comfort Criteria
		Strolling' in all seasons
Pedestrian Transit / Thoroughfare (A-B)	For access to and passage through the development and surrounding area	'Pedestrian Transit / Thoroughfare (A-B)' in all seasons

6.1.3. Mitigation Requirements

The assessment considers the requirement for mitigation schemes at each location based on proposed pedestrian activities listed in Appendix C. Areas that **require** mitigation schemes in order to create a wind environment sufficiently safe and comfortable for proposed uses are highlighted.

6.2. Opening day scenario

The results of the assessment for the opening day scenario, i.e. the proposed stadium within existing surrounds, with proposed shop, first floor of the health centre and opening day podium, are summarised in graphical format in Figures 6.1a and 6.1b.

6.2.1. Safety

Wind conditions in and around the site are generally rated as suitable, in terms of safety, for use by the general public. However, exceptions to this do occur:

- Around the South-East of the stadium [Locations 54, 56, 58, 59 and 73]

where conditions rate as safe for the able bodied, but unsuitable for the general public.

6.2.2. Comfort

6.2.2.1. Thoroughfares

Wind conditions at leisure thoroughfares in and around the site are generally rated as suitable, in terms of pedestrian comfort, for the intended use, with the exception of those to the South-East of the stadium [Locations 52, 55, 56, 57 and 73] where conditions are at best suitable for pedestrian transit.

For the thoroughfare located to the South-East of the stadium that is intended for pedestrian transit only [Location 58], wind conditions are too windy for comfortable thoroughfare in the absence of mitigation, being rated as uncomfortable for all uses.

6.2.2.2. Entrances

Wind conditions at entrances to the proposed stadium are considered unsuitable, in terms of pedestrian comfort, for ingress/egress from the building in the absence of mitigation measures.

Wind conditions at entrances in and around the rest of the proposed development are considered suitable, in terms of pedestrian comfort, for ingress/egress from the building.

6.2.2.3. Recreational spaces

Wind conditions at all recreational spaces in and around the site, are considered suitable, in terms of pedestrian comfort, for the intended use throughout the year.

6.2.2.4. Outdoor Seating

Wind conditions at the outdoor seating area to the East of the proposed shop [Location 67] are considered unsuitable, in terms of pedestrian comfort, for the intended use, being suitable only for short term standing / sitting during summer in the absence of mitigation.

6.3. Opening day scenario with soft landscaping and mitigation measures

The results of the assessment for the impact of proposed soft landscaping, as discussed in Section 3.3.1, and wind mitigation measures, discussed in Section 3.4.1, on the opening day scenario are summarised in graphical format in Figures 6.2a and 6.2b.

6.3.1. Safety

With the introduction of the proposed soft landscaping and wind mitigation measures, wind conditions in and around the site are considered suitable, in terms of safety, for use by the general public.

6.3.2. Comfort

6.3.2.1. Thoroughfares

With the introduction of the proposed soft landscaping and wind mitigation measures, wind conditions at the majority of thoroughfares in and around the site remain suitable, or are improved such that they become suitable, in terms of pedestrian comfort, for the intended use.

A single exception to this remains to the South-East [Location 56] where conditions are rated as suitable, in terms of pedestrian comfort, for pedestrian

transit only during the winter months, but is otherwise rated as suitable for the intended uses as leisure thoroughfare throughout the rest of the year.

6.3.2.2. Entrances

With the introduction of the proposed soft landscaping and wind mitigation measures, wind conditions at all entrances in and around the site remain suitable, or are improved such that they become suitable, in terms of pedestrian comfort, for ingress/egress from the buildings.

6.3.2.3. Recreational Spaces

With the introduction of the proposed soft landscaping and wind mitigation measures, wind conditions at all recreational spaces in and around the site, remain suitable, in terms of pedestrian comfort, for the intended use throughout the year.

6.3.2.4. Outdoor Seating

With the introduction of the proposed soft landscaping and wind mitigation measures, wind conditions at the outdoor seating area to the East of the proposed shop are improved such that they become suitable, in terms of pedestrian comfort, for the intended use.

6.4. Completed podium

The results of the assessment for the completed podium, i.e. the proposed stadium within existing surrounds, with proposed shop, completed health centre and completed podium, including the proposed soft landscaping, as discussed in Section 3.3.2, and wind mitigation measures, discussed in Section 3.4.1, are summarised in graphical format in Figures 6.3a and 6.3b.

6.4.1. Safety

With the introduction of the completed podium and additional soft landscaping, wind conditions in and around the site remain suitable, in terms of safety, for use by the general public.

6.4.2. Comfort

6.4.2.1. Thoroughfares

With the introduction of the completed podium and additional soft landscaping, wind conditions at all thoroughfares in and around the site remain suitable, or are improved such that they become suitable, in terms of pedestrian comfort, for the intended use.

6.4.2.2. Entrances

With the introduction of the completed podium and additional soft landscaping, wind conditions at all entrances in and around the site remain suitable, in terms of pedestrian comfort, for ingress/egress from the buildings.

6.4.2.3. Recreational Spaces

With the introduction of the completed podium and additional soft landscaping, wind conditions at all recreational spaces in and around the site, remain suitable, in terms of pedestrian comfort, for the intended use throughout the year.

6.4.2.4. Outdoor Seating

With the introduction of the completed podium and additional soft landscaping, wind conditions at the outdoor seating area to the East of the proposed shop remain suitable, in terms of pedestrian comfort, for the intended use.

6.5. Completed hotel

The results of the assessment for the completed hotel, i.e. the proposed stadium within existing surrounds, with proposed shop, hotel, completed health centre and completed podium, including the proposed soft landscaping, as discussed in Section 3.3.2, and wind mitigation measures, discussed in Section 3.4.1, are summarised in graphical format in Figures 6.4a and 6.4b.

6.5.1. Safety

With the introduction of the proposed hotel, wind conditions in and around the site remain suitable, in terms of safety, for use by the general public.

6.5.2. Comfort

6.5.2.1. Thoroughfares

With the introduction of the proposed hotel, wind conditions at the majority of thoroughfares in and around the site remain suitable, in terms of pedestrian comfort, for the intended use.

However, windier conditions to the South-West of the stadium result in location 21 becoming suitable for pedestrian transit only during the winter months. Conditions in this area are otherwise rated as suitable for the intended uses as leisure thoroughfare throughout the rest of the year.

6.5.2.2. Entrances

With the introduction of proposed hotel, wind conditions at the all entrances in and around the site remain suitable, in terms of pedestrian comfort, for ingress/egress from the building.

6.5.2.3. Recreational spaces

With the introduction of proposed hotel, wind conditions at recreational spaces in and around the site generally remain suitable, in terms of pedestrian comfort, for the intended use throughout the year. However, an exception occurs at the base of the proposed hotel to the North [Locations 22 and 23] where windier conditions prevail.

6.5.2.4. Outdoor Seating

With the introduction of the proposed hotel, wind conditions at the outdoor seating area to the East of the proposed shop become unsuitable, in terms of pedestrian comfort, for the intended use, being suitable for short term standing / sitting as opposed to longer term sitting.

6.6. Completed sports development

The results of the assessment for the completed hotel, i.e. the proposed stadium within existing surrounds, with proposed shop, hotel, sports development, completed health centre and completed podium, including the proposed soft landscaping, as discussed in Section 3.3.2, and wind mitigation measures, discussed in Section 3.4.1, are summarised in graphical format in Figures 6.5a and 6.5b.

6.6.1. Safety

With the introduction of the proposed sports development, wind conditions in and around the site remain suitable, in terms of safety, for use by the general public.

6.6.2. Comfort

6.6.2.1. Thoroughfares

With the introduction of the proposed sports development, wind conditions at the majority of thoroughfares in and around the site remain suitable, in terms of pedestrian comfort, for the intended use, with the aforementioned exception at location 21 which is suitable for pedestrian transit only during the winter months.

6.6.2.2. Entrances

With the introduction of proposed sports development, wind conditions at entrances in and around the site generally remain suitable, in terms of pedestrian comfort, for the intended use.

However, the entrances to the East of the hotel [Locations 26 and 29] become unsuitable, in terms of pedestrian comfort, for ingress/egress from the building.

6.6.2.3. Recreational spaces

With the introduction of proposed sports development, wind conditions at recreational spaces in and around the site generally remain suitable, in terms of pedestrian comfort, for the intended use throughout the year.

However, whilst wind conditions at location 23 become suitable, in terms of pedestrian comfort, for the intended use, wind conditions to the East of the hotel [Location 68] and in the central podium area [Location 52] become unsuitable for comfortable recreational uses, being suitable only for strolling.

6.6.2.4. Outdoor Seating

With the introduction of the proposed sports development, wind conditions at the outdoor seating area to the East of the proposed shop [Location 67] remain unsuitable, in terms of pedestrian comfort, for the intended use.

6.7. Completed masterplan

The results of the assessment for the completed masterplan, i.e. the proposed stadium within existing surrounds, with proposed shop, hotel, health centre, sport and residential developments, in the absence of the proposed landscaping and wind mitigation measures are summarised in graphical format in Figure 6.6.

6.7.1. Safety

Wind conditions in and around the site are generally rated as suitable, in terms of safety, for use by the general public. However, exceptions to this do occur:

- Around the South-East of the stadium [Location 58]
- Between the residential towers [Location 62]
- Around the South-East corner of the residential development [Location 40]

where conditions rate as safe for the able bodied, but unsuitable for the general public, in the absence of mitigation.

6.7.2. Comfort

6.7.2.1. Thoroughfares

Wind conditions at all thoroughfares in and around the site are considered suitable, in terms of pedestrian comfort, for the intended use.

6.7.2.2. Entrances

Wind conditions at entrances to the proposed stadium are considered unsuitable, in terms of pedestrian comfort, for ingress/egress from the building in the absence of mitigation measures.

However, wind conditions at entrances in and around the rest of the proposed development are considered suitable, in terms of pedestrian comfort, for ingress/egress from the building.

6.7.2.3. Recreational spaces

Wind conditions at recreational spaces in and around the podium area are generally considered suitable, in terms of pedestrian comfort, for the intended use. Exceptions to this occur between the hotel and sports development [Locations 23 and 24], on the podium of the sports development [Location 31] where windier conditions prevail.

However, wind conditions at recreational spaces within the residential development are largely unsuitable, in terms of pedestrian comfort, for the intended use in the absence of mitigation measures. Exceptions to this occur at the southern extent of the podium [Locations 64 & 66] and the base of the south-eastern tower [Location 63] where conditions are rated as suitable, in terms of pedestrian comfort, for the intended use.

6.7.3. Health Centre

Whilst conditions around the health centre on the North-East podium have not been directly assessed within the wind tunnel for the completed masterplan scenario. It is expected that, with the inclusion of the relevant wind mitigation measures discussed in section 3.4.1, wind conditions in this area will remain suitable, both in terms of safety and pedestrian comfort, for the intended uses.

6.8. Completed masterplan with proposed soft landscaping and wind mitigation measures

The results of the assessment for the impact of proposed soft landscaping, as discussed in Section 3.3.3, and wind mitigation measures, as discussed in section 3.4.2, on the completed masterplan are summarised in graphical format in Figure 6.7.

6.8.1. Safety

With the introduction of the proposed soft landscaping and wind mitigation measures, wind conditions in and around the site are considered suitable, in terms of safety, for use by the general public.

6.8.2. Comfort

6.8.2.1. Thoroughfares

With the introduction of the proposed soft landscaping and wind mitigation measures, wind conditions at all thoroughfares in and around the site remain suitable, in terms of pedestrian comfort, for the intended use.

6.8.2.2. Entrances

With the introduction of the proposed soft landscaping and wind mitigation measures, wind conditions at all entrances in and around the site are considered suitable, in terms of pedestrian comfort, for ingress/egress from the buildings.

6.8.2.3. Recreational spaces

With the introduction of the proposed soft landscaping and wind mitigation measures, wind conditions at recreational spaces in and around the site are generally considered suitable, in terms of pedestrian comfort, for the intended use. A single exception to this remains between the residential towers [Location 61] where windier conditions prevail, and while conditions are suitable for general recreational uses during summer they are suitable only for strolling during spring and autumn.

6.8.2.4. Balconies

Wind conditions within balcony areas are considered suitable, in terms of pedestrian comfort, for the intended use as outdoor seating, with the exception of the balconies at the top of the tallest tower of the residential development [Locations 103 and 104] where wind conditions are suitable for outdoor viewing only.

7. Recommendations for Further Mitigation

In order to further enhance the local wind microclimate and to ensure the presence of amenable conditions at all locations within the site and surrounding area for the completed masterplan, it is recommended to develop further soft landscaping proposals / mitigation measures, which might include, but would not be limited to those outlined below, and to verify the effectiveness of these via wind tunnel testing.

- Enhanced soft landscaping and/or localised screening between the towers of the residential development
- Raised parapets on the balconies of the residential development

8. Conclusions

The boundary layer wind tunnel study has assessed the wind microclimate for the proposed development. On the basis of the wind tunnel modelling, the following conclusions have been drawn:

- In the absence of soft landscaping and wind mitigation measures, pedestrian wind conditions are generally considered suitable in terms of pedestrian comfort and/or safety for planned activities. However, several exceptions to this occur both in terms of pedestrian safety and comfort.
- With the introduction of proposed landscaping and wind mitigation, all locations in and around the site are considered suitable in terms of pedestrian safety, throughout the year and for all phases of construction.
- While the majority of locations are considered comfortable for the intended use with the introduction of proposed landscaping and wind mitigation, there are some areas that remain unsuitable in terms of pedestrian comfort during the various construction stages and for the completed masterplan

Mitigation measures that would be expected to address the remaining unwelcome wind conditions for the completed masterplan have been identified. However, it is recommended that the effectiveness of these solutions be verified via wind tunnel testing.

9. References

[1] Davenport, A.G. *An Approach to Human Comfort Criteria for Environmental Wind Conditions*. Colloqium on Building Climatology, Stockholm, September 1972.

[2] Lawson, T.V. *The Wind Environment of Buildings: A Logical Approach to the Establishment of Criteria*. University of Bristol, Department of Aeronautical Engineering, TVL/7301, 1973.

[3] Lawson, T.V. *The determination of the wind environment of a building complex before construction.* University of Bristol, Department of Aeronautical Engineering, TVL/9025, 1990.

[4] ESDU (Engineering Science Data Unit) Item 01008. *Computer program for wind speeds and turbulence properties: flat or hilly sites in terrain with roughness*. 2001.

Figure 3.1: Site location

Figure 3.2: Plan view of the proposed development

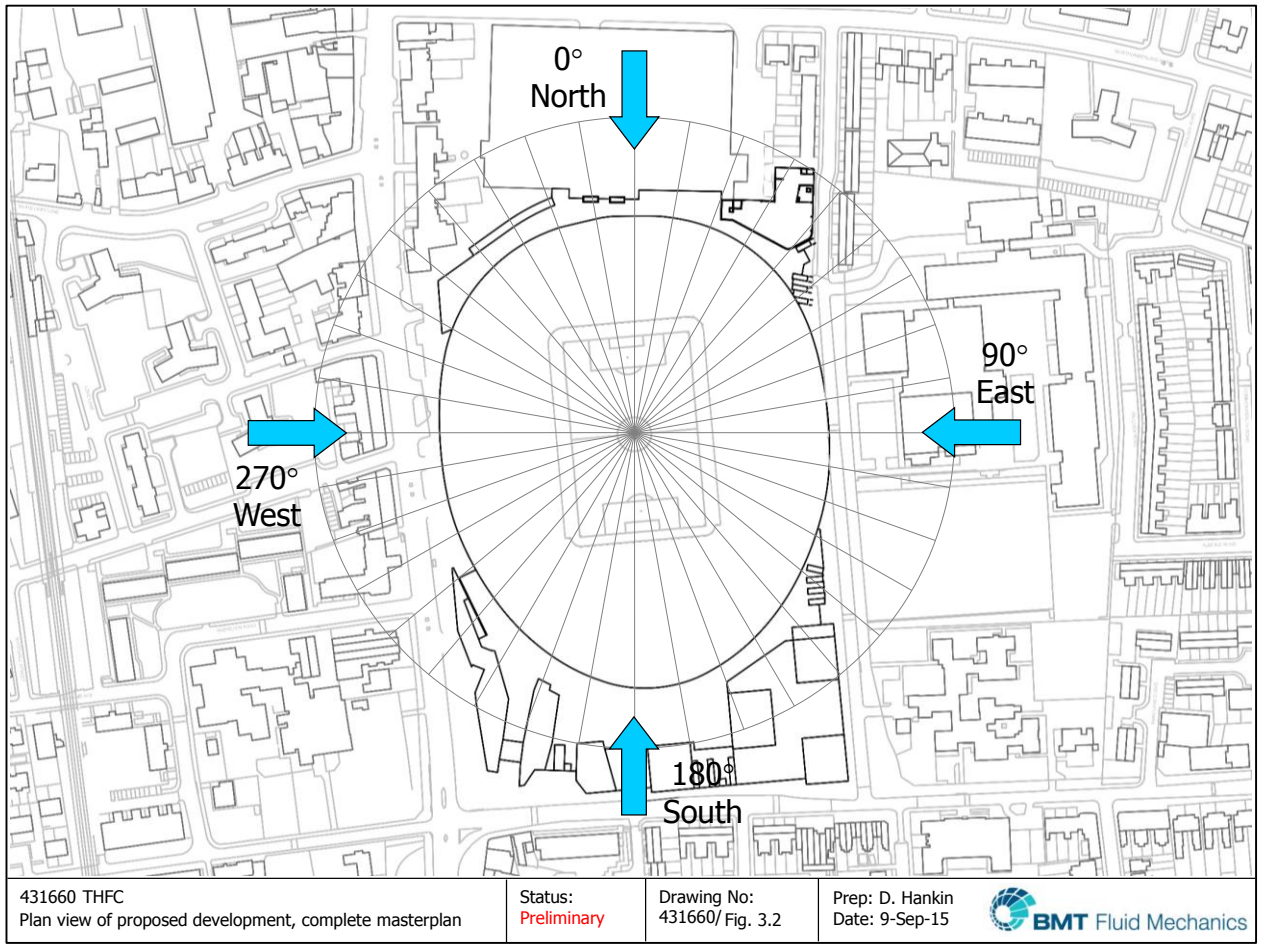


Figure 3.3a: Soft landscaping proposals, opening day scenario

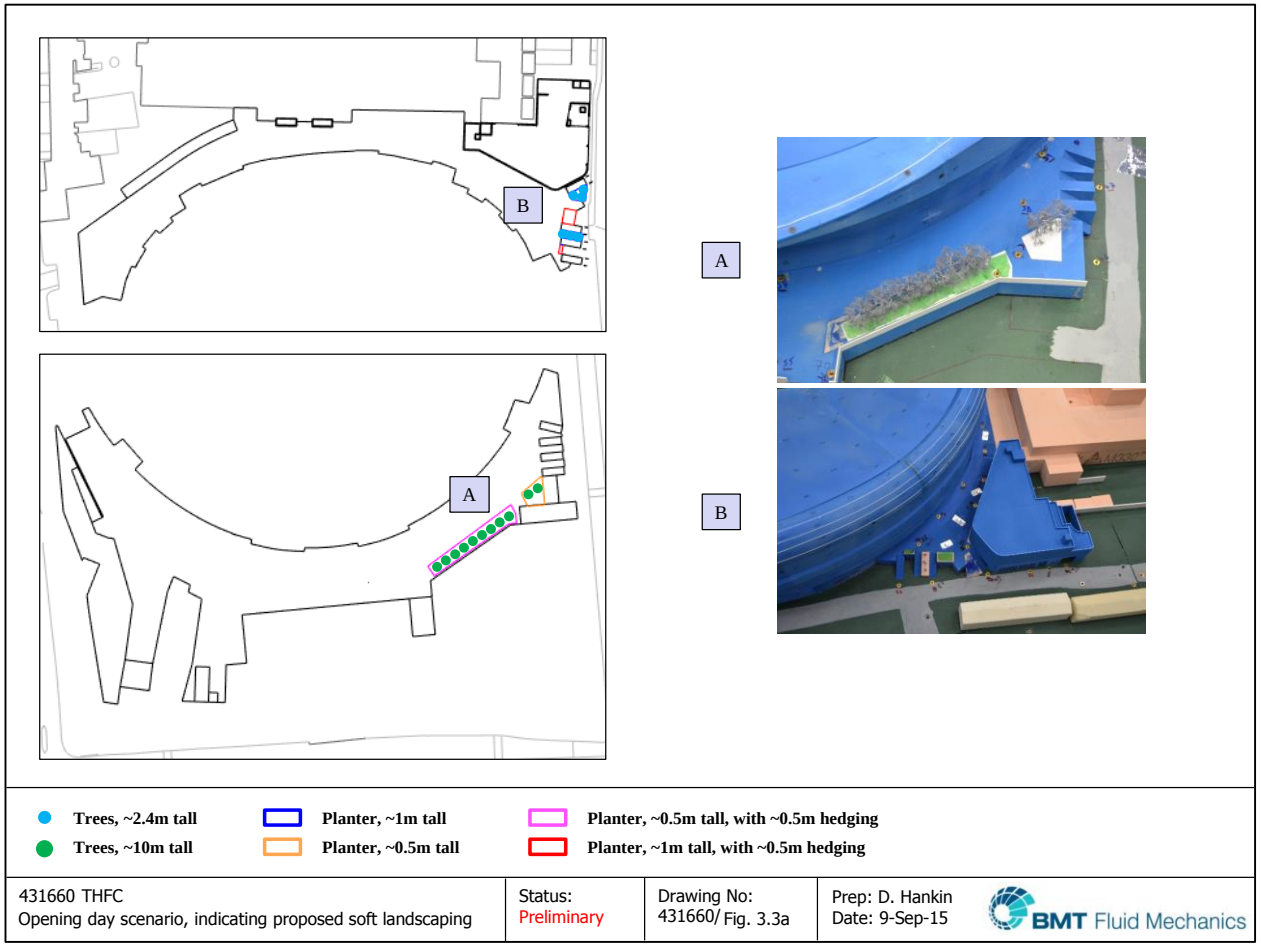


Figure 3.3b: Soft landscaping proposals, construction phases

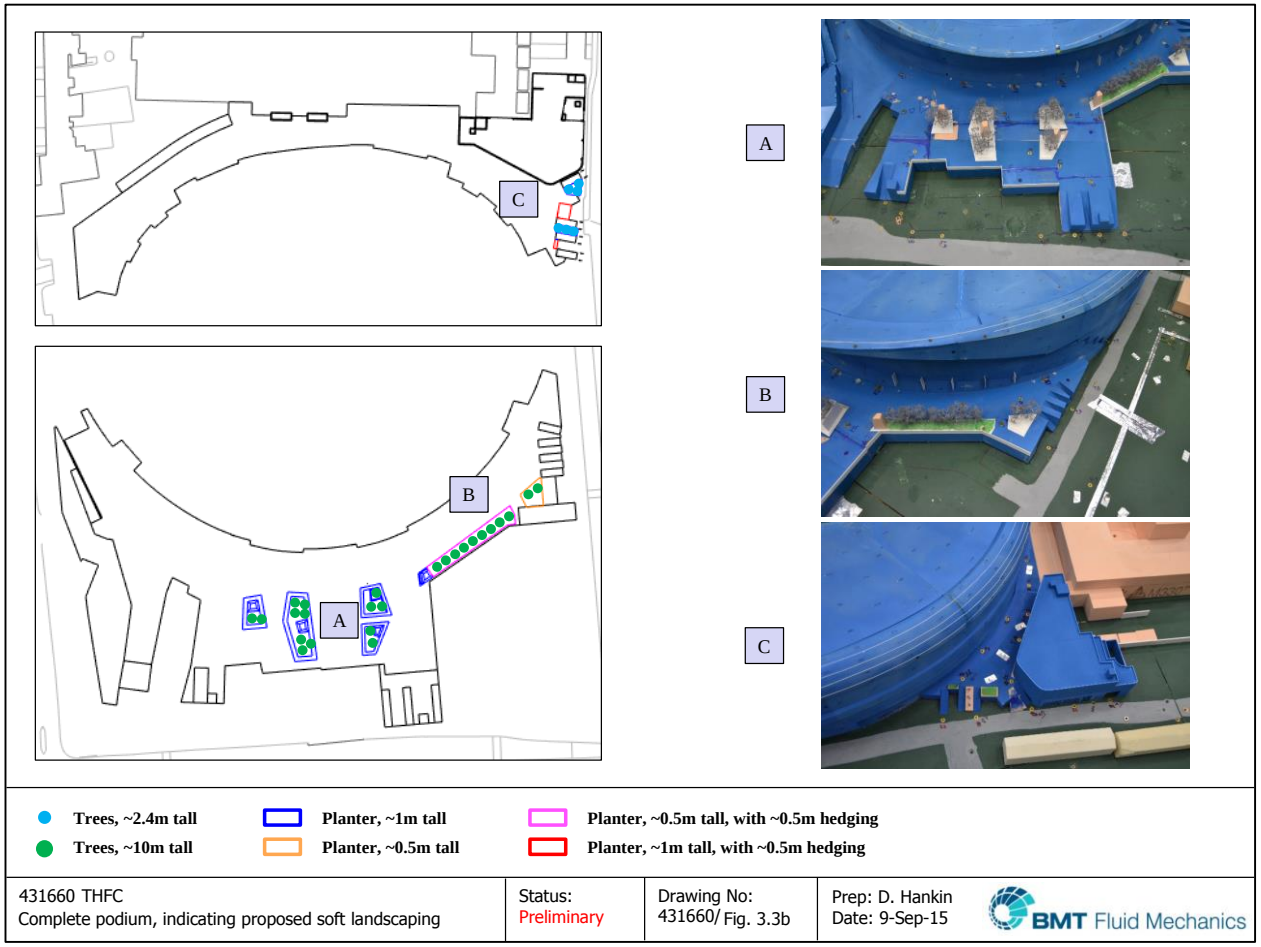


Figure 3.3c: Soft landscaping proposals, completed masterplan

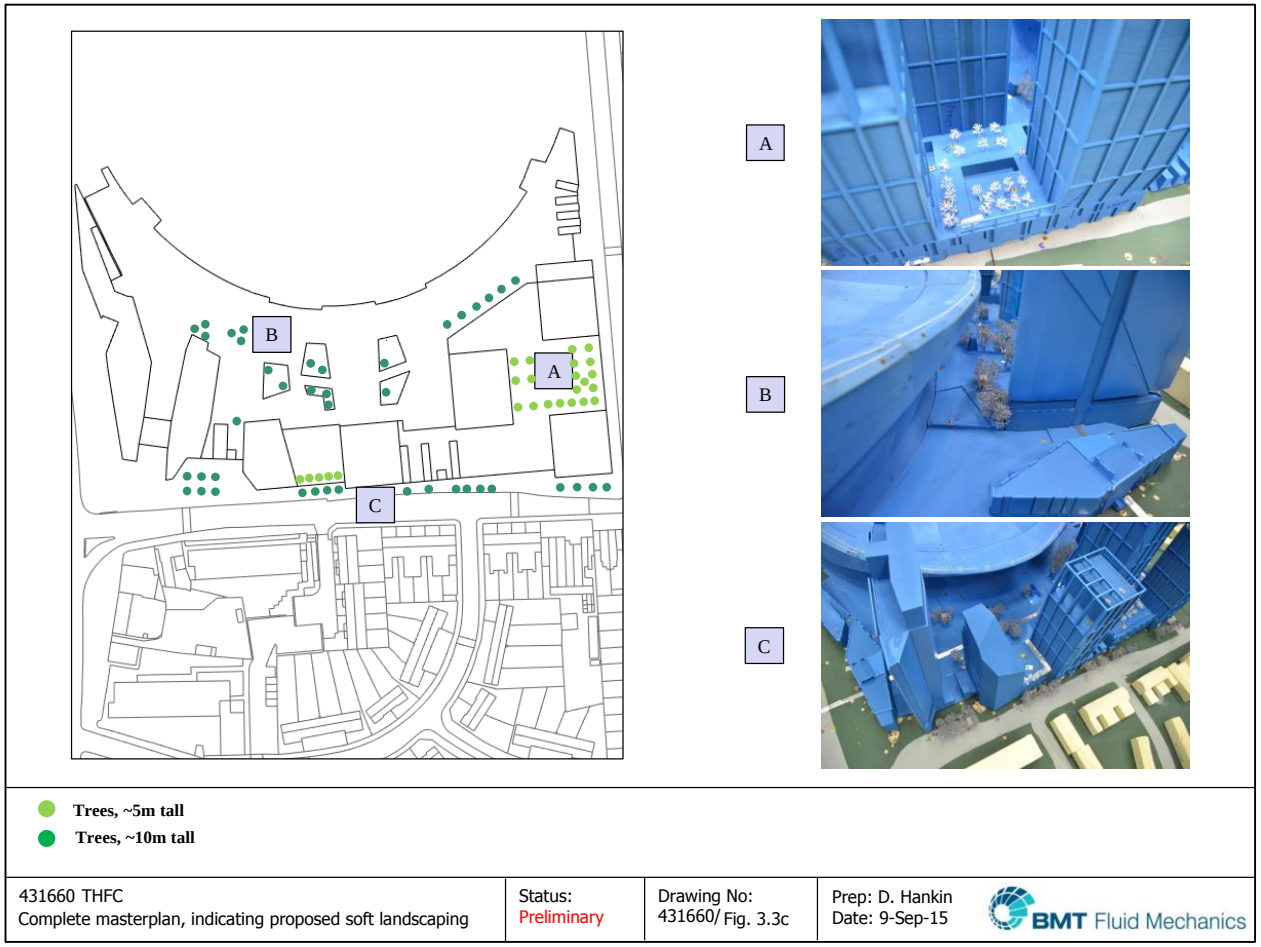


Figure 3.4a: Wind mitigation measures, opening day and construction phases

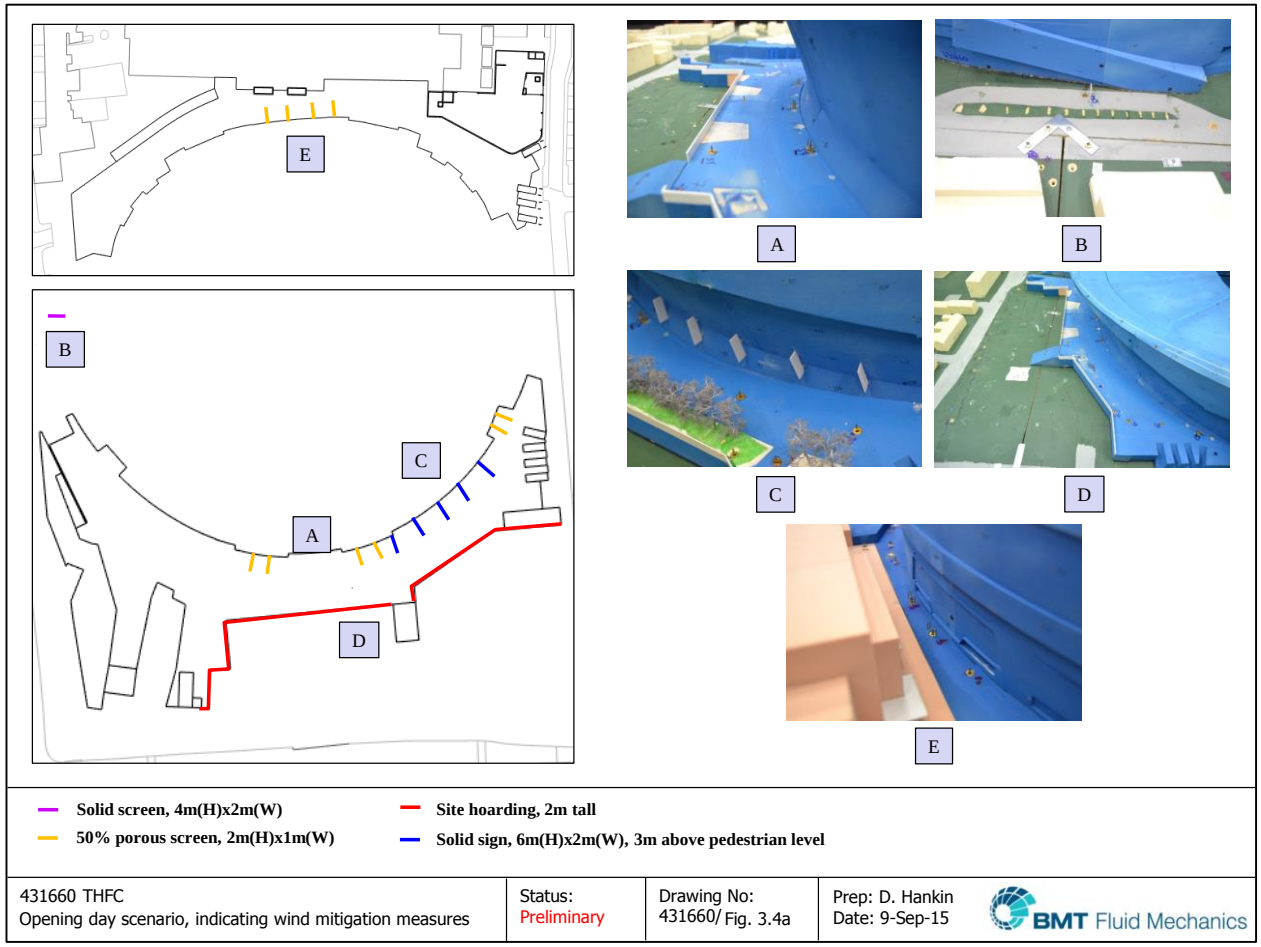


Figure 3.4b: Wind mitigation measures, completed masterplan

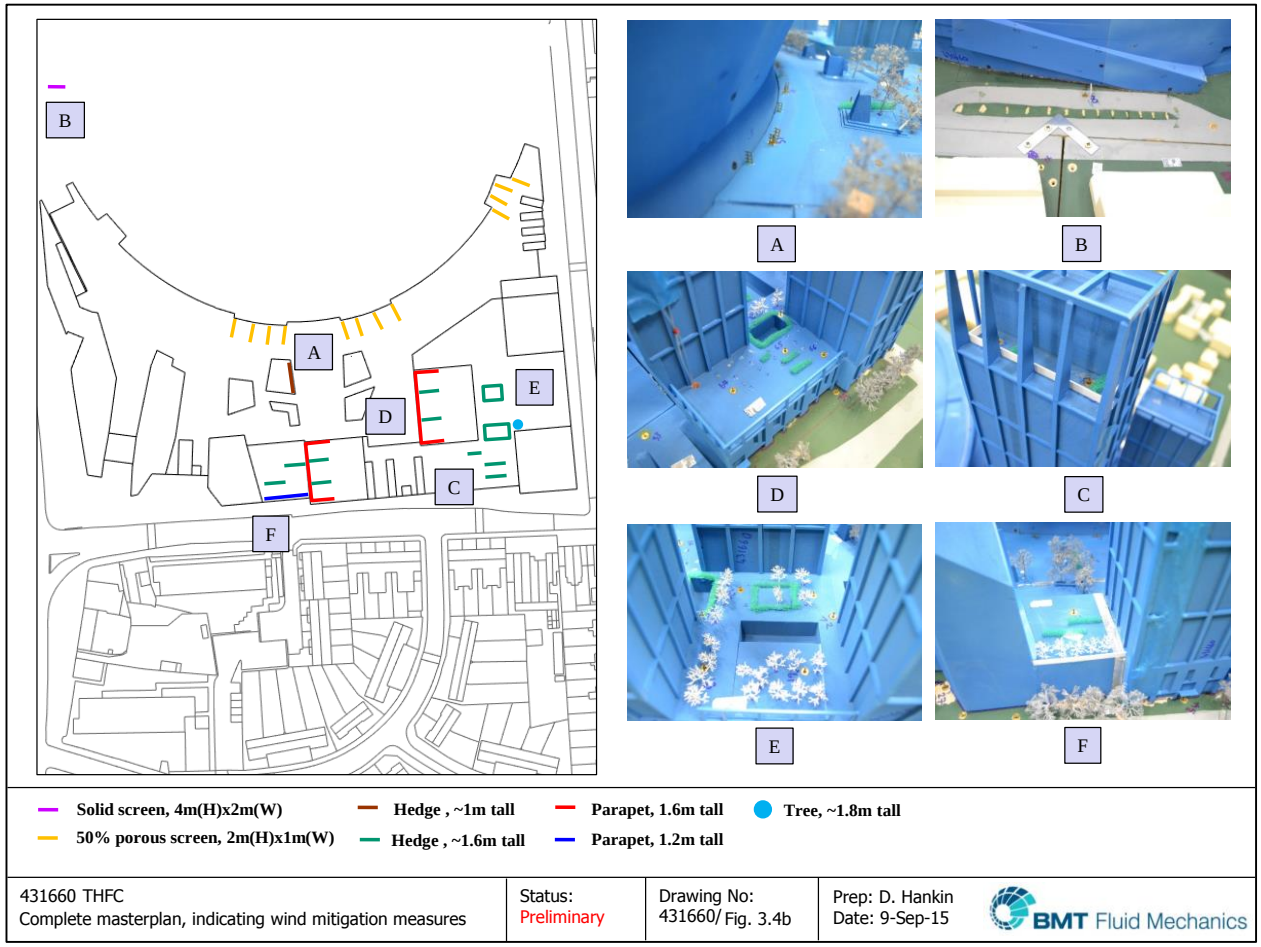


Figure 6.1a: Wind microclimate summary, the opening day scenario, southern podium area

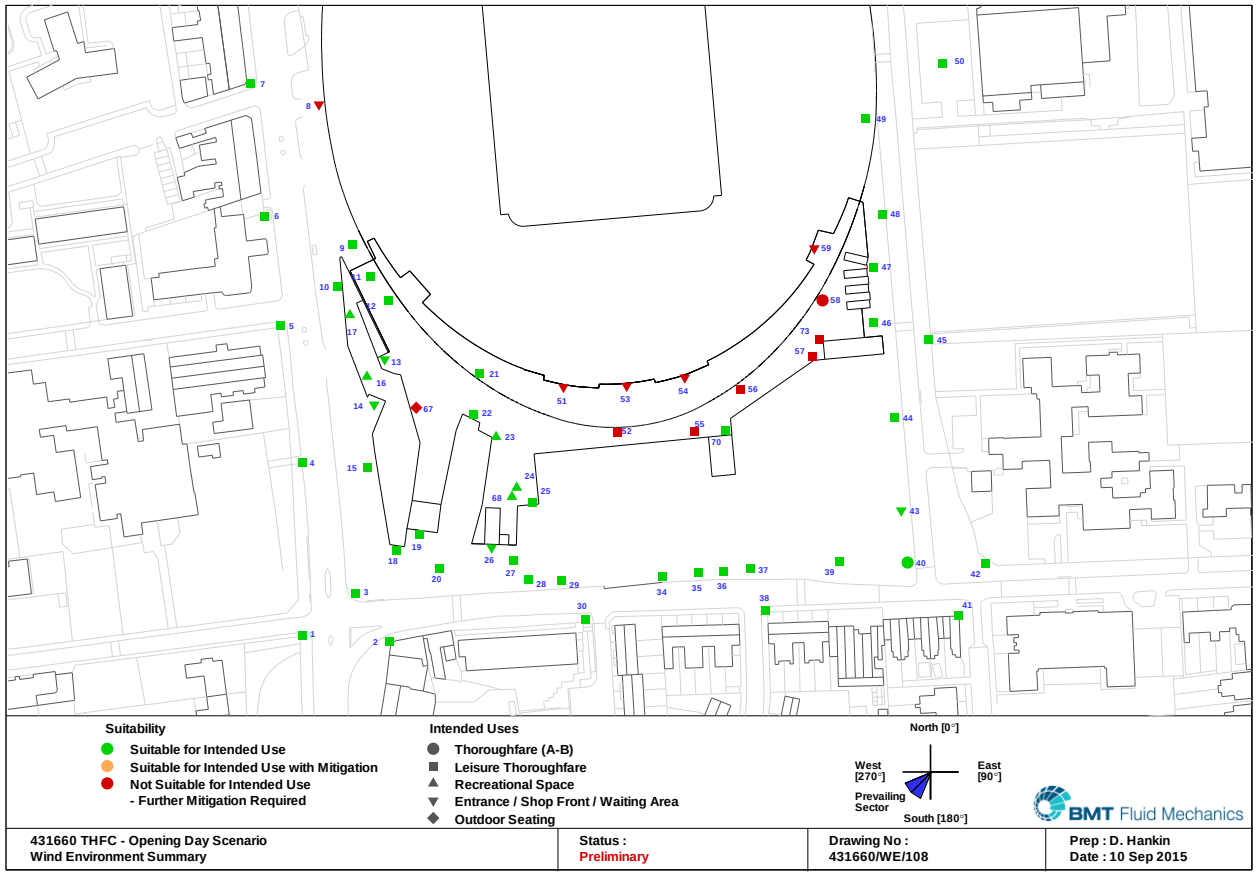


Figure 6.1b: Wind microclimate summary, the opening day scenario, northern podium area

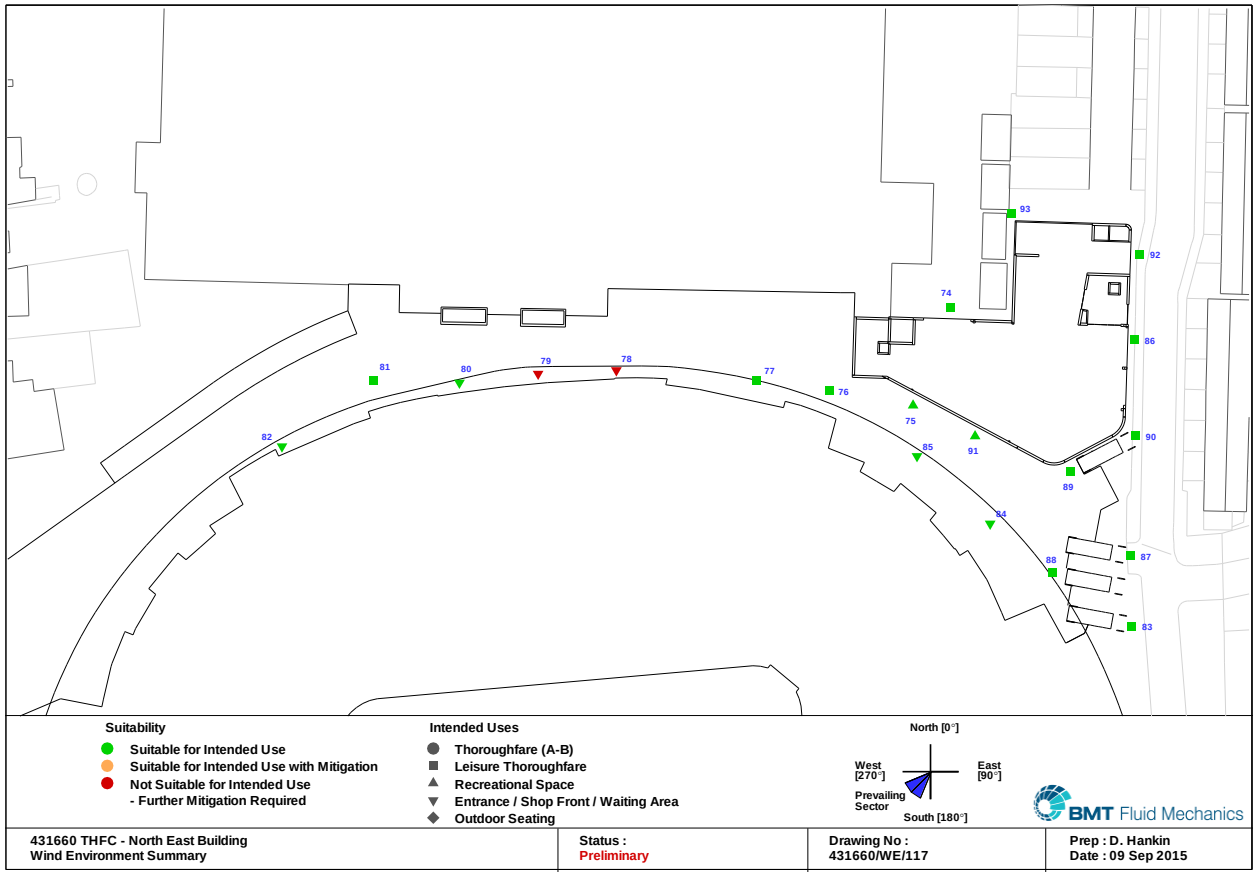


Figure 6.2a: Wind microclimate summary, the opening day scenario, southern podium area, with soft landscaping and wind mitigation

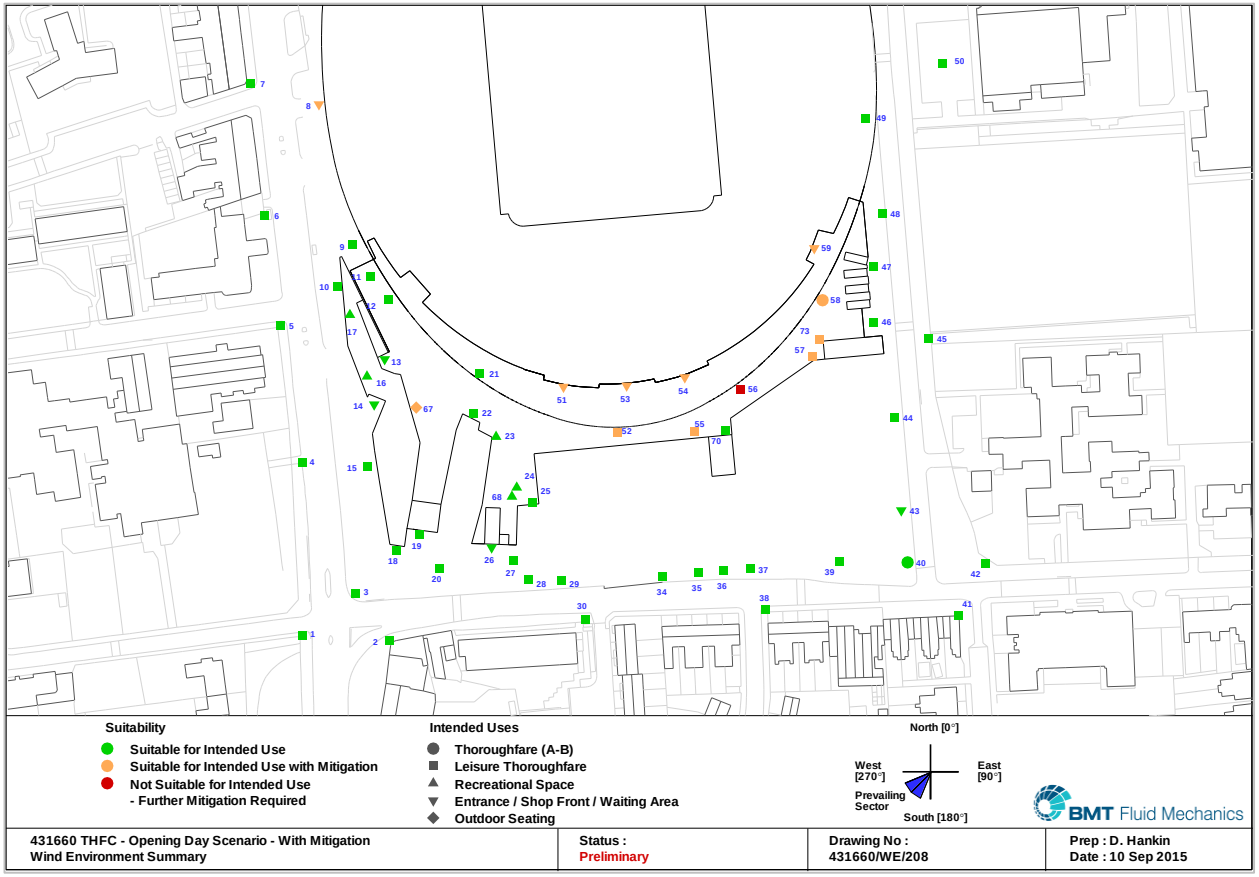


Figure 6.2b: Wind microclimate summary, the opening day scenario, northern podium area, with soft landscaping and wind mitigation

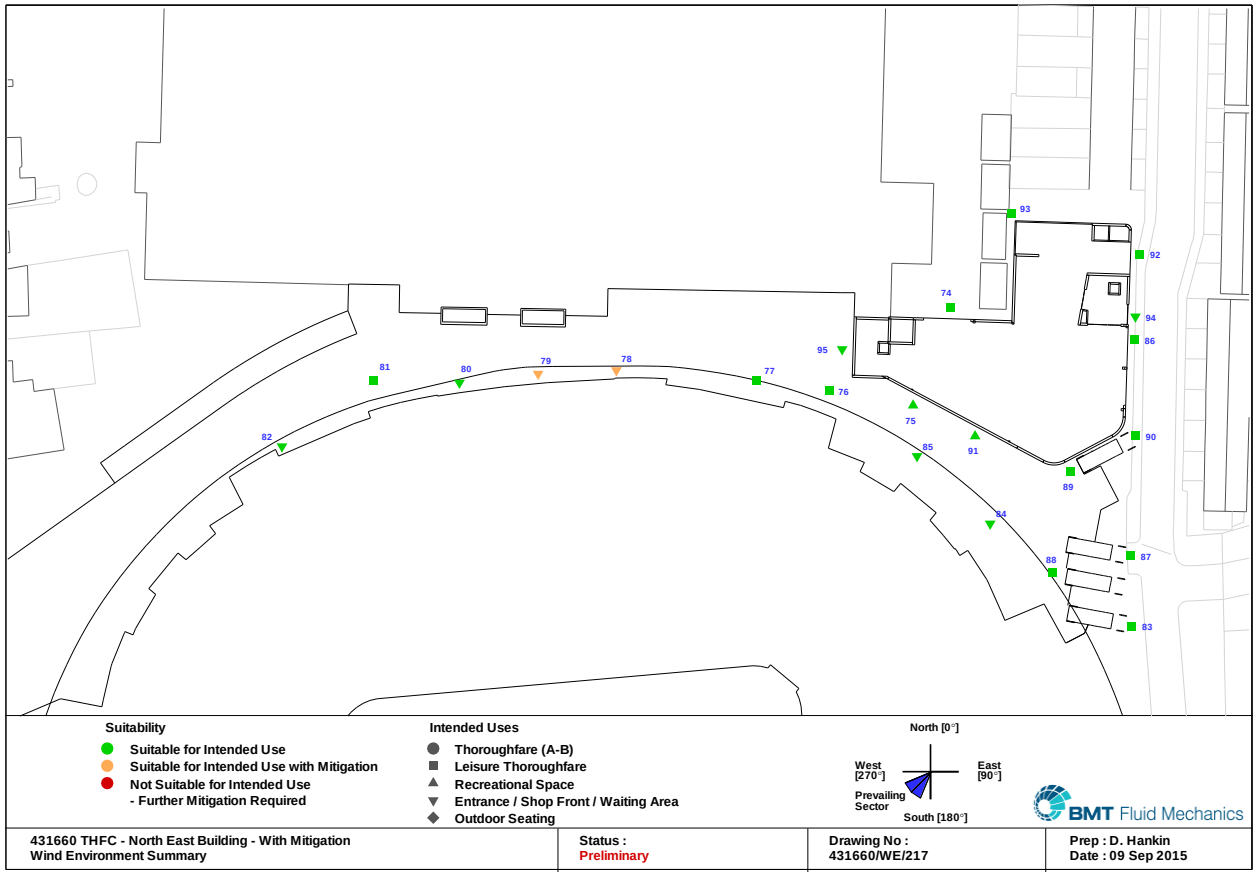


Figure 6.3a: Wind microclimate summary, the completed podium, southern podium area, with soft landscaping and wind mitigation

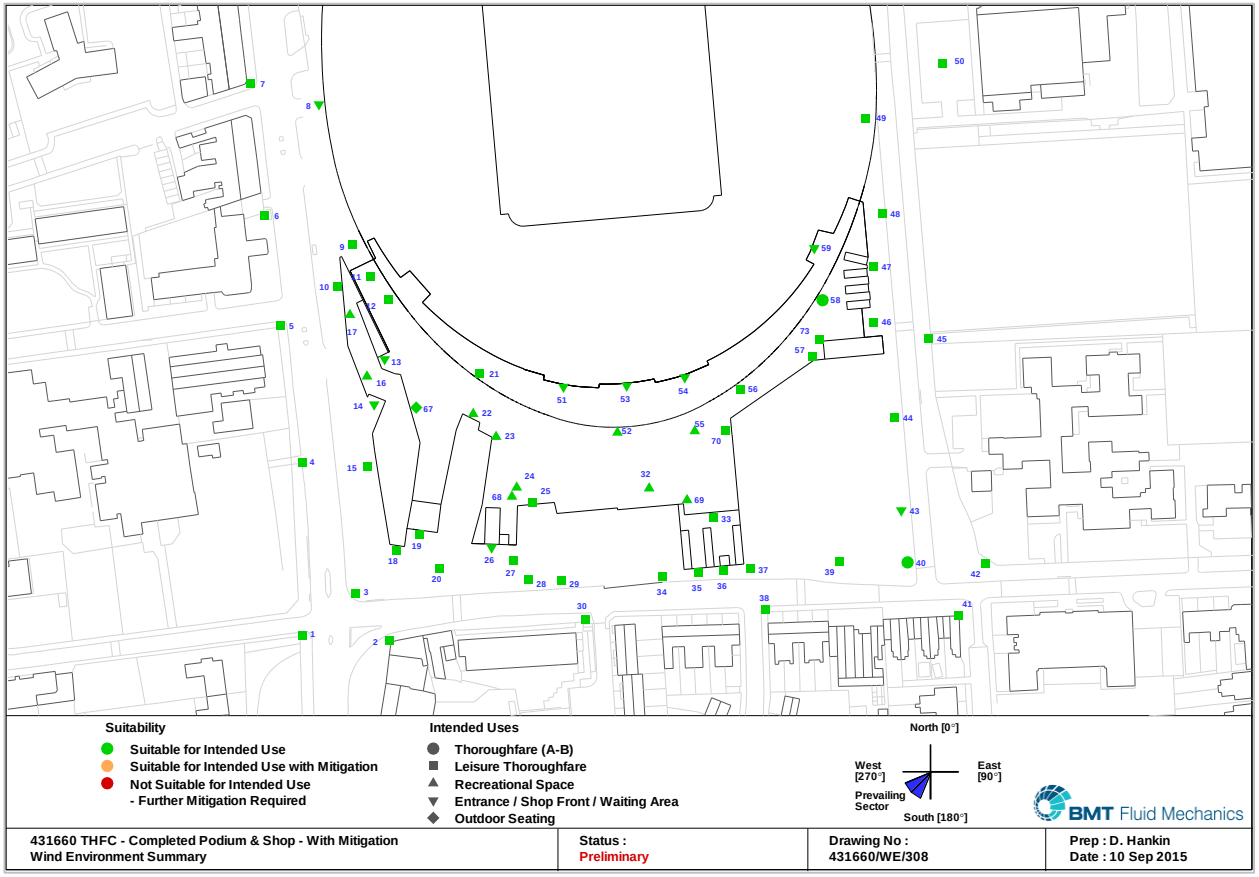


Figure 6.3b: Wind microclimate summary, the completed podium, northern podium area, with soft landscaping and wind mitigation

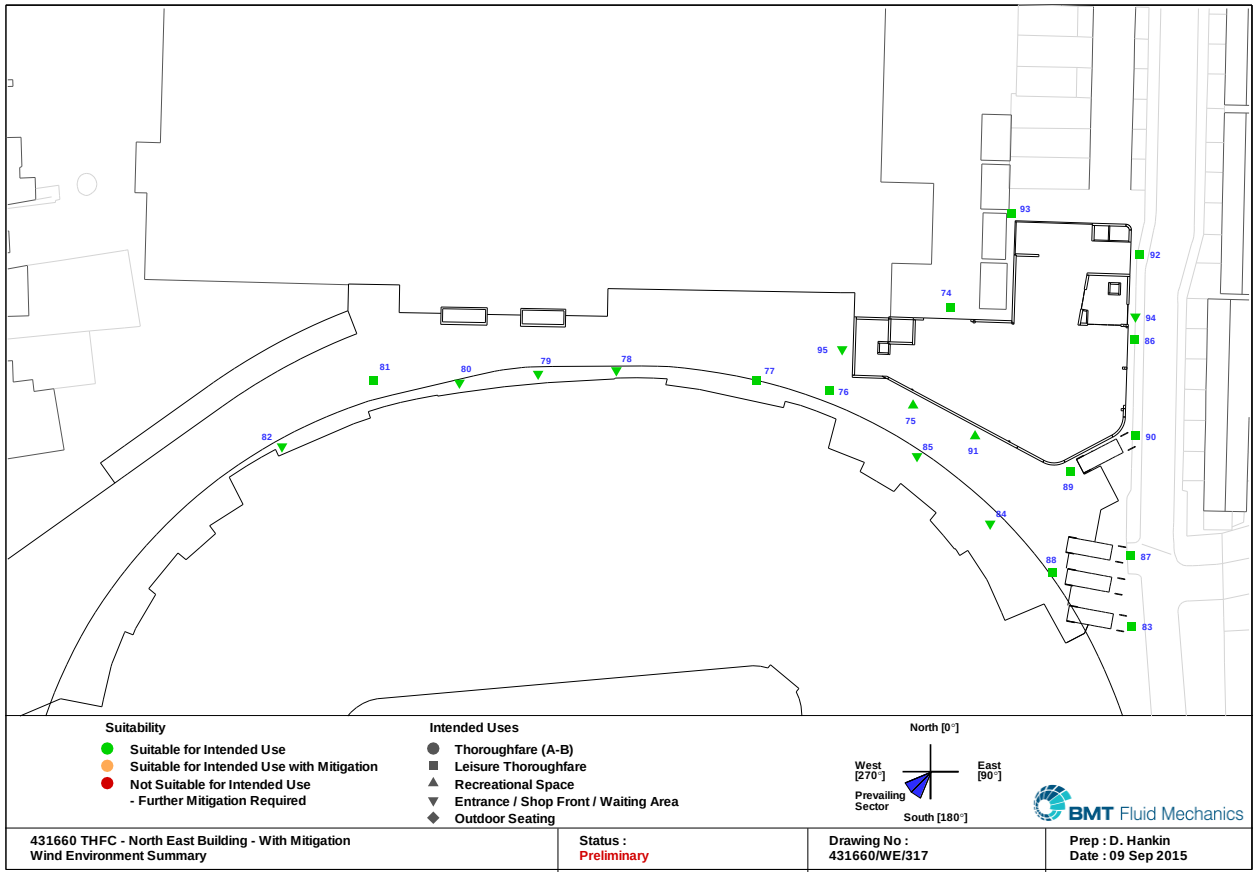


Figure 6.4a: Wind microclimate summary, the completed hotel, southern podium area, with soft landscaping and wind mitigation

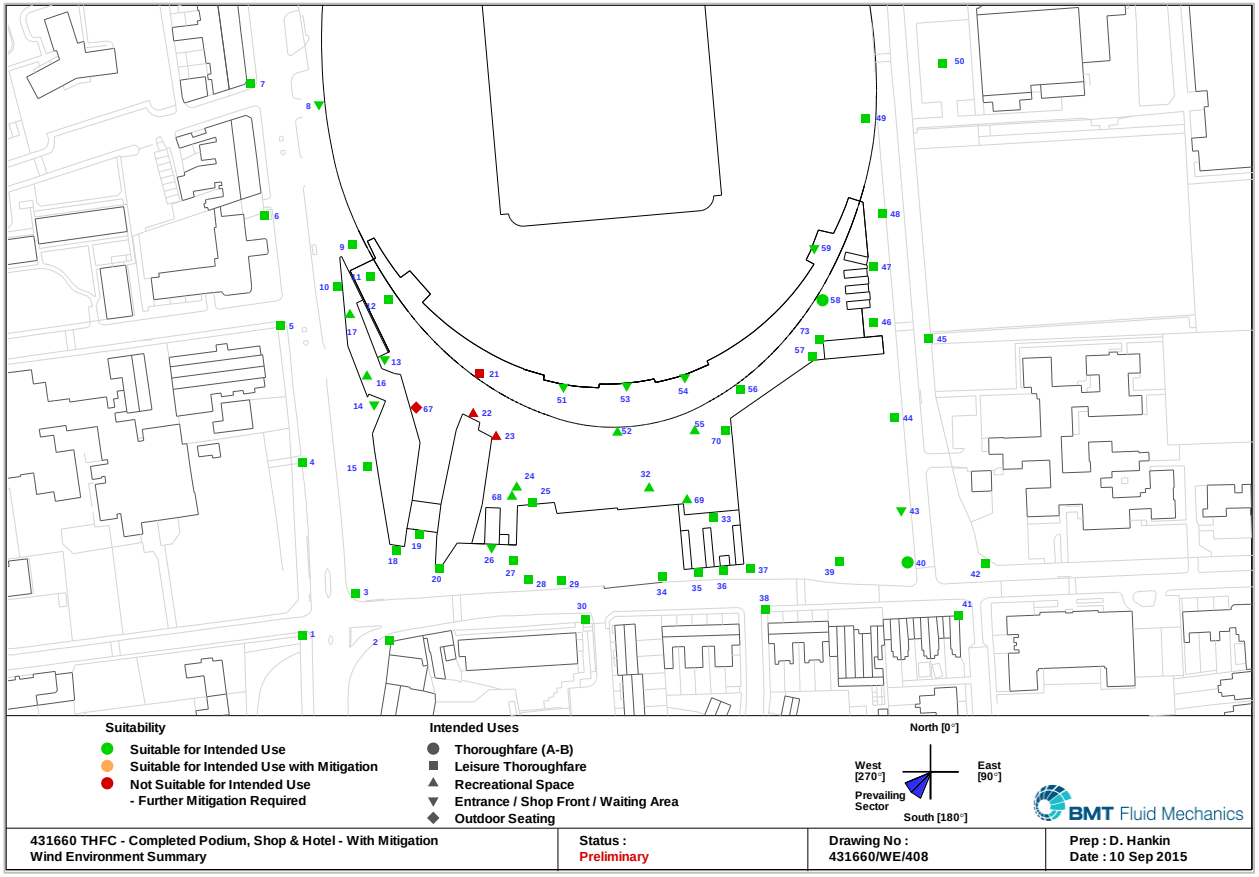


Figure 6.4b: Wind microclimate summary, the completed hotel, northern podium area, with soft landscaping and wind mitigation

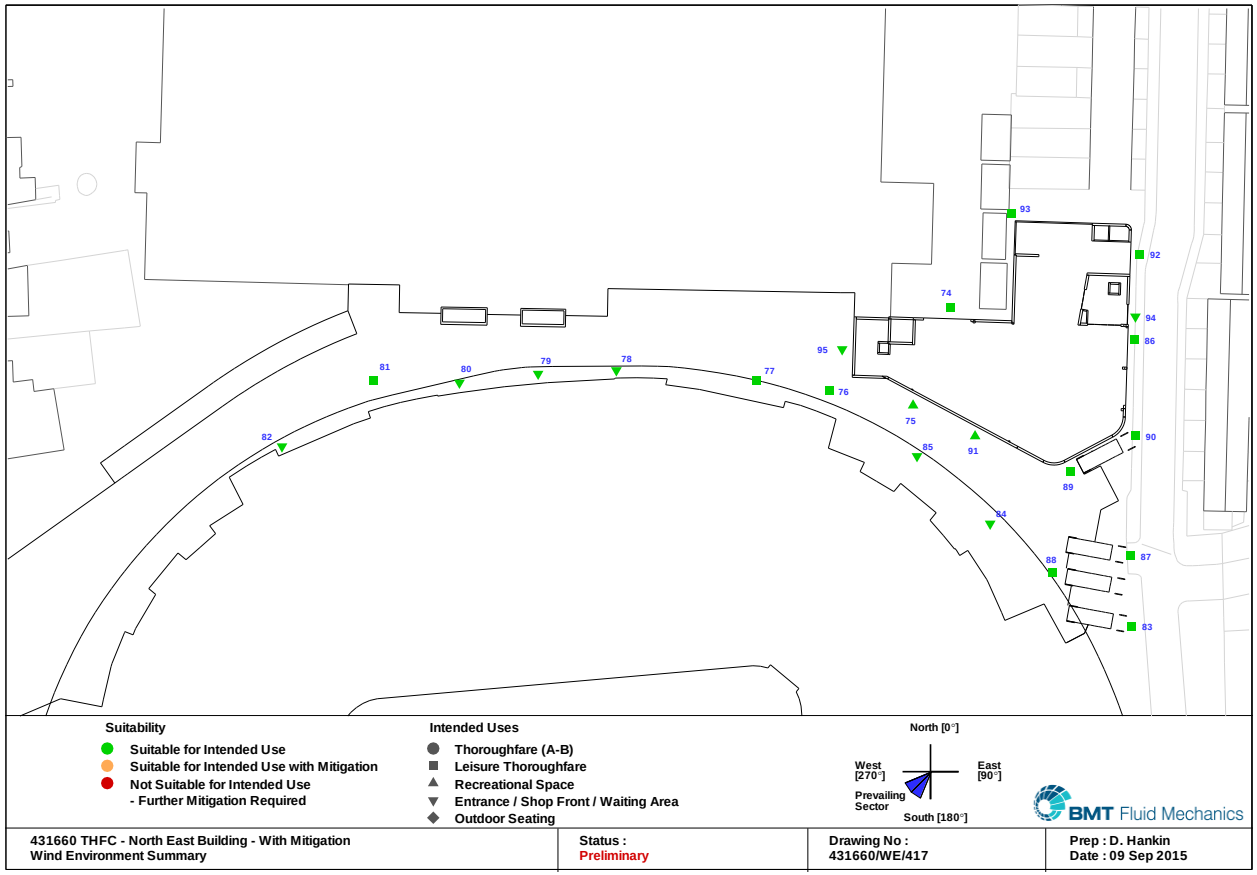


Figure 6.5a: Wind microclimate summary, the completed sports development, southern podium area, with soft landscaping and wind mitigation

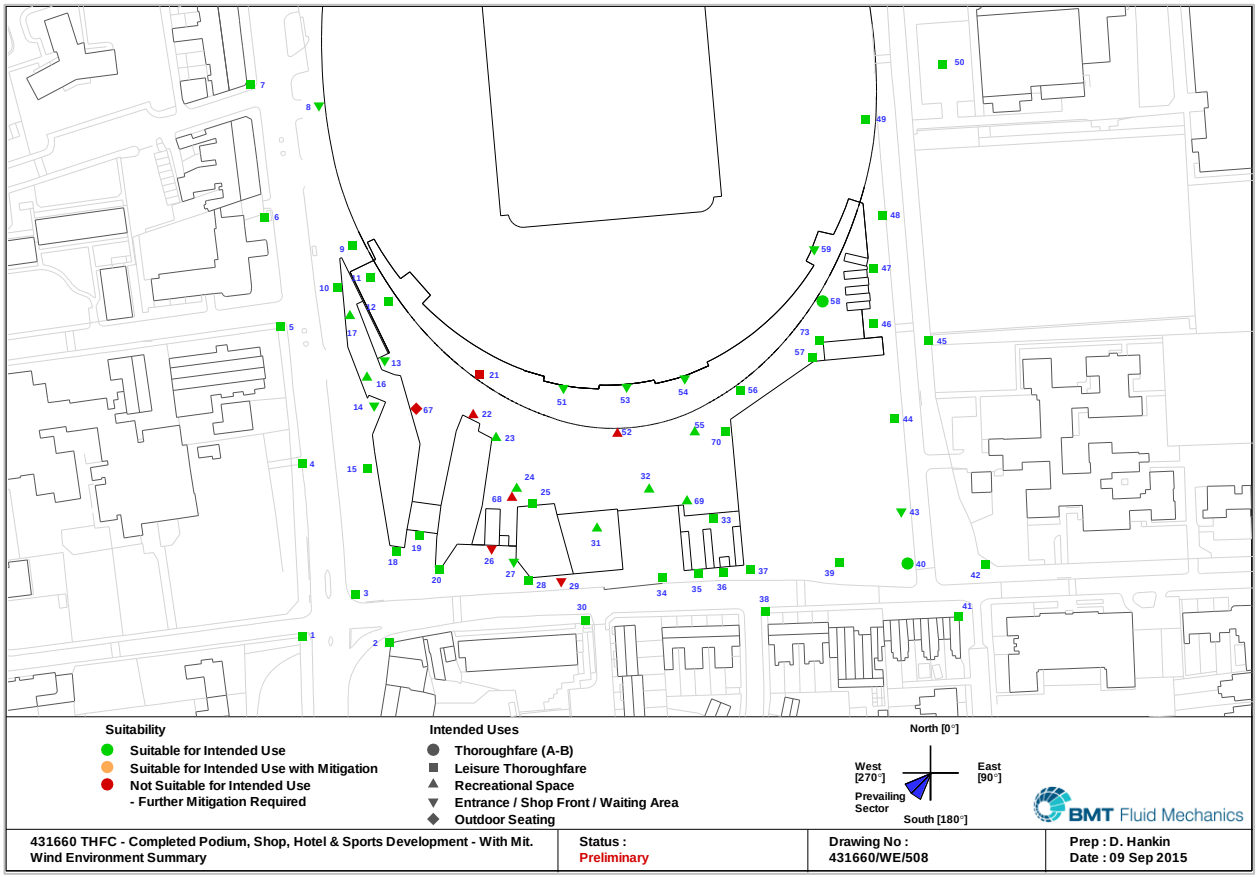


Figure 6.5b: Wind microclimate summary, the completed sports development, northern podium area, with soft landscaping and wind mitigation

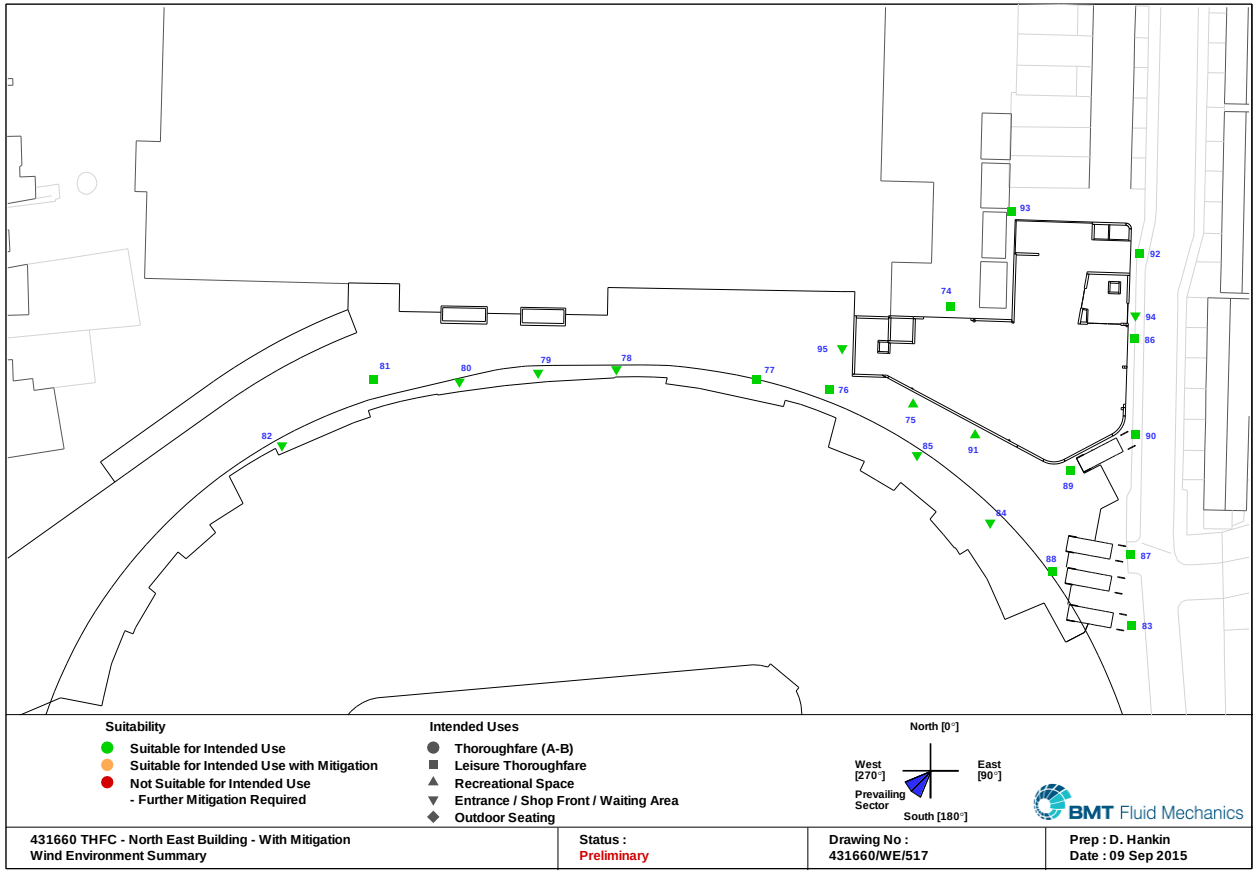


Figure 6.6: Wind microclimate summary, the completed masterplan, southern podium area

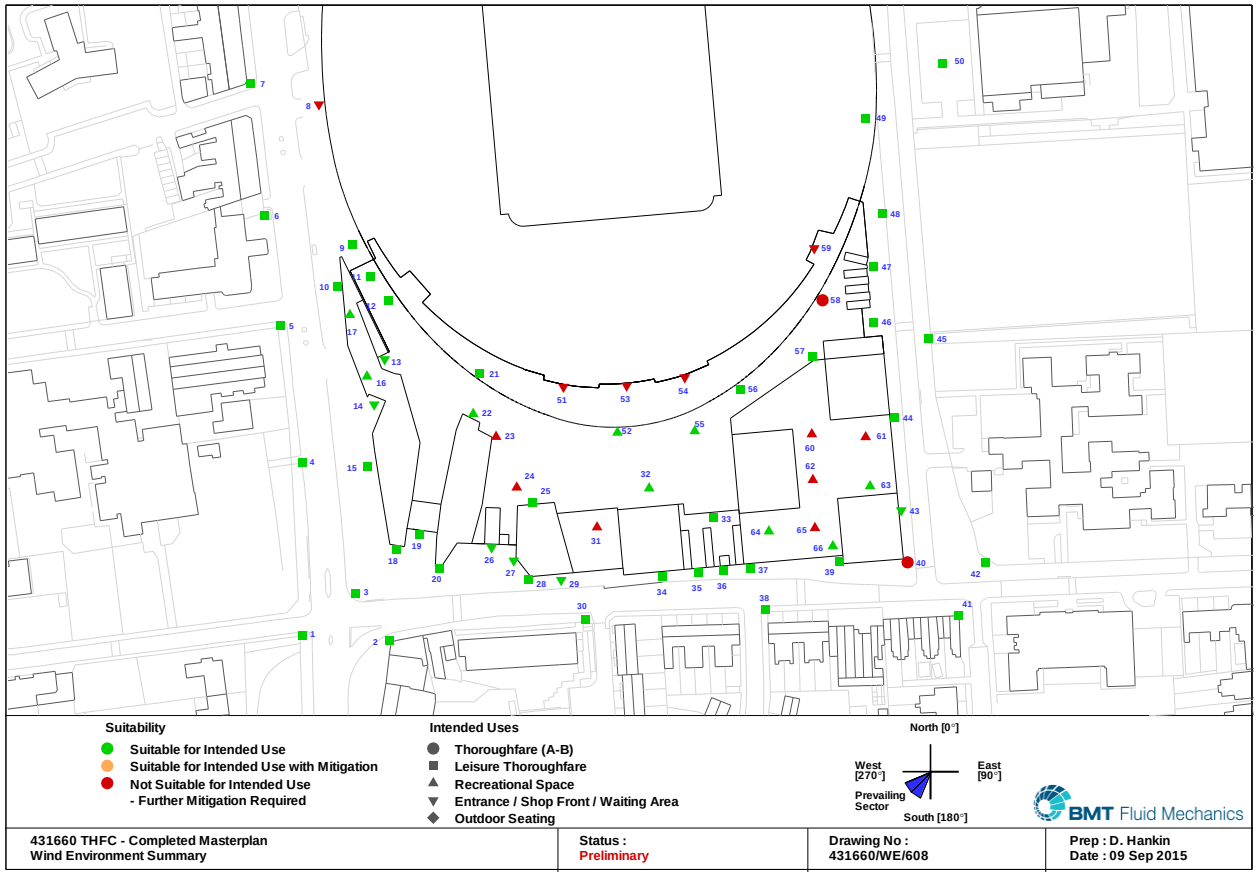
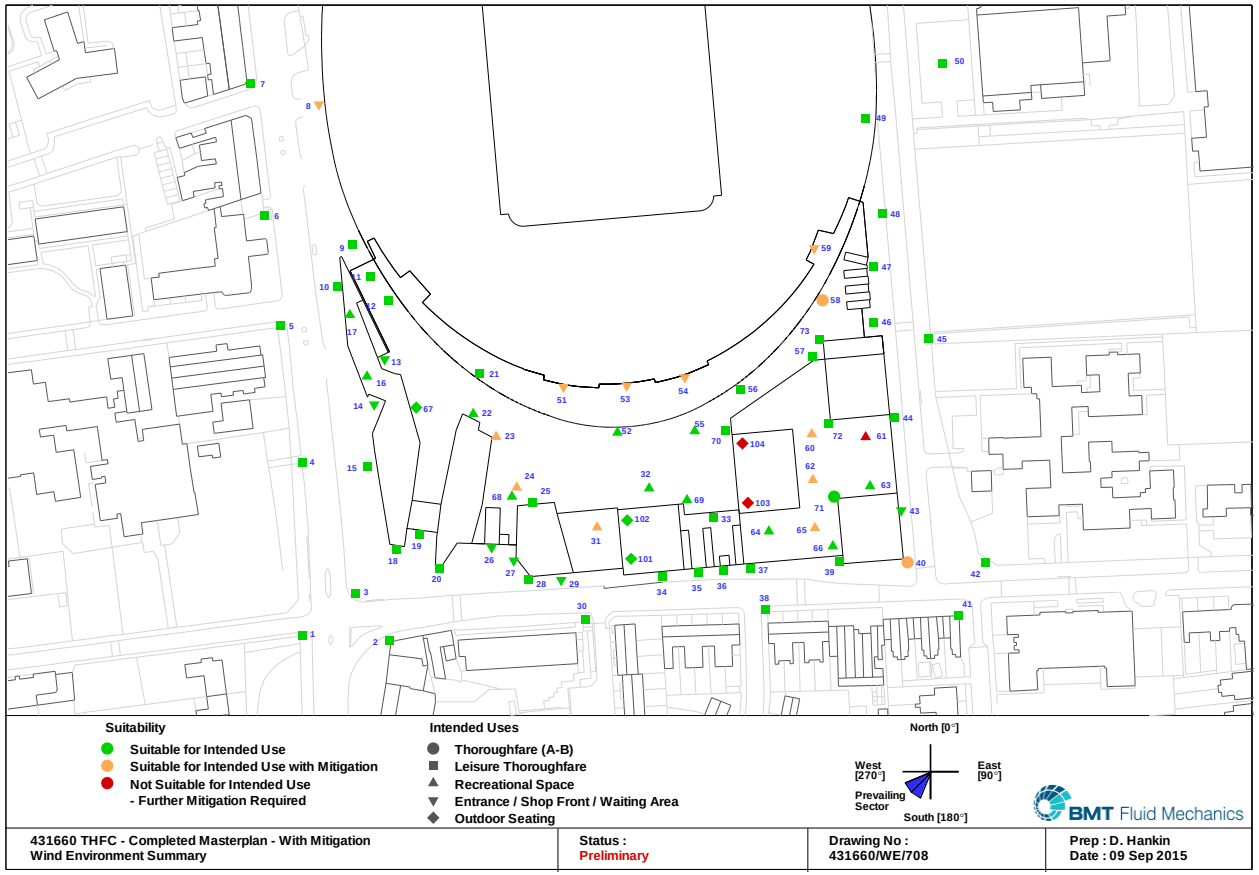


Figure 6.7: Wind microclimate summary, the completed masterplan, southern podium area, with soft landscaping and wind mitigation



APPENDIX A. WIND CLIMATE ANALYSIS

A.1. ESDU Wind Analysis

A detailed analysis was carried out to determine the wind properties at the site. The wind analysis is based on the widely accepted Deaves and Harris model of the atmospheric boundary layer (ABL), as defined in ESDU Item 01008[4], and has provided wind profiles describing the variation of wind speed and turbulence intensity with height and wind direction. From this analysis representative profiles were defined as targets for the ABL simulation in the wind tunnel.

A.1.1. Terrain Roughness Changes for ESDU Wind Analysis

The wind analysis takes detailed account of the variation of the upwind terrain on each wind sector. The roughness changes used in the analysis for the current study are given in Table A.1 below.

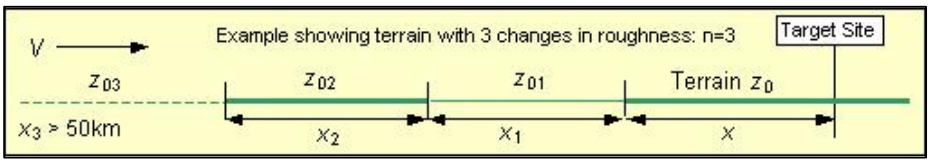
Table A.1: Terrain roughness changes from the site

Wind Dir	z_0 [m]	x_0 [m]	z_{01} [m]	x_{01} [m]	z_{02} [m]	x_{02} [m]	z_{03} [m]
0°	0.3	7940	0.03				
30°	0.3	9640	0.03				
60°	0.3	12910	0.03				
90°	0.3	19050	0.03				
120°	0.3	22710	0.03				
150°	0.3	27860	0.03				
180°	0.3	7260	0.55	5680	0.3	20170	0.03
210°	0.3	7260	0.6	7230	0.3	21170	0.03
240°	0.3	31670	0.03				
270°	0.3	26870	0.03				
300°	0.3	12920	0.03				
330°	0.3	8260	0.03				

Where
x_0 = upwind fetch
z_0 = roughness length

z0

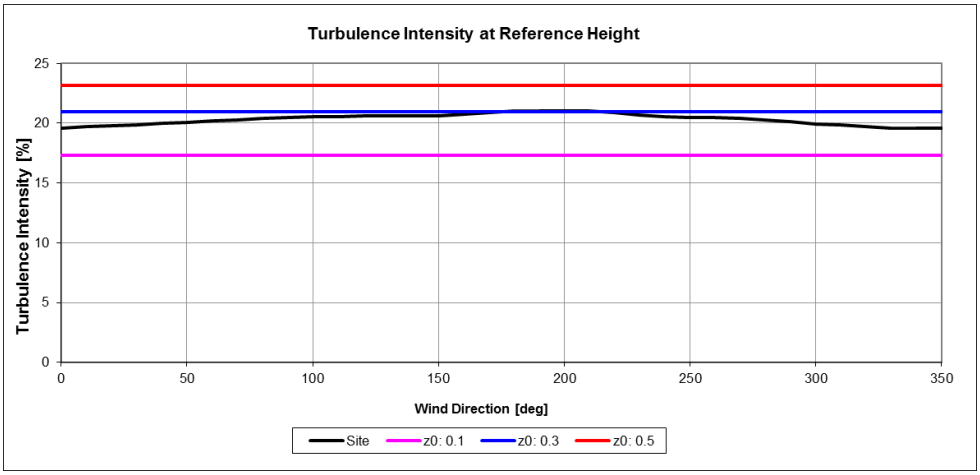
water	=	sea, lakes, estuaries
0.03	=	open country
0.1	=	sparse suburban
0.3	=	suburban
0.5	=	urban
0.7 / 1.0	=	city centre



A.2. Wind Properties at the Site

Figure A.1 shows the variation of longitudinal turbulence intensity with wind direction at a reference height of 50m.

Figure A.1: Variation of turbulence intensity with wind direction at 50m height, including reference turbulence levels



Due to the similarity of wind properties with wind direction, one target profile has been selected for the boundary layer simulation.

The target profile selected for the boundary layer simulation is that for 210°

Figures A.2 and A.3 show the variation of mean wind-speed (normalised by the mean wind speed at the reference height of 50m) and turbulence intensity with height for winds approaching the site from the four primary quarters.

Figure A.2: Variation of mean wind speed normalised by mean wind speed at a reference height of 50m

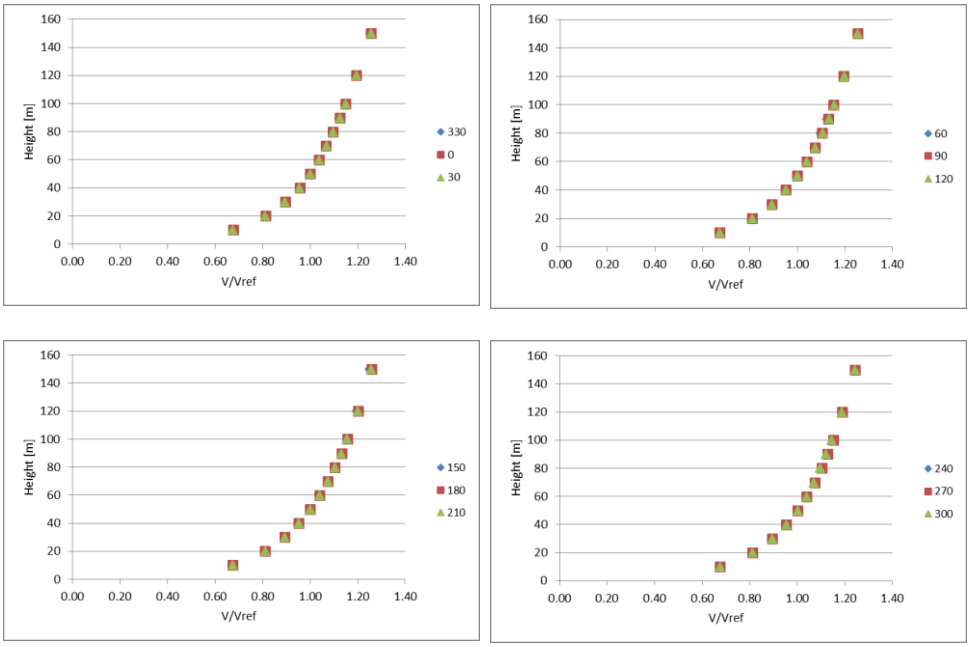


Figure A.3: Variation of longitudinal turbulence intensity with wind direction a reference height of 50m

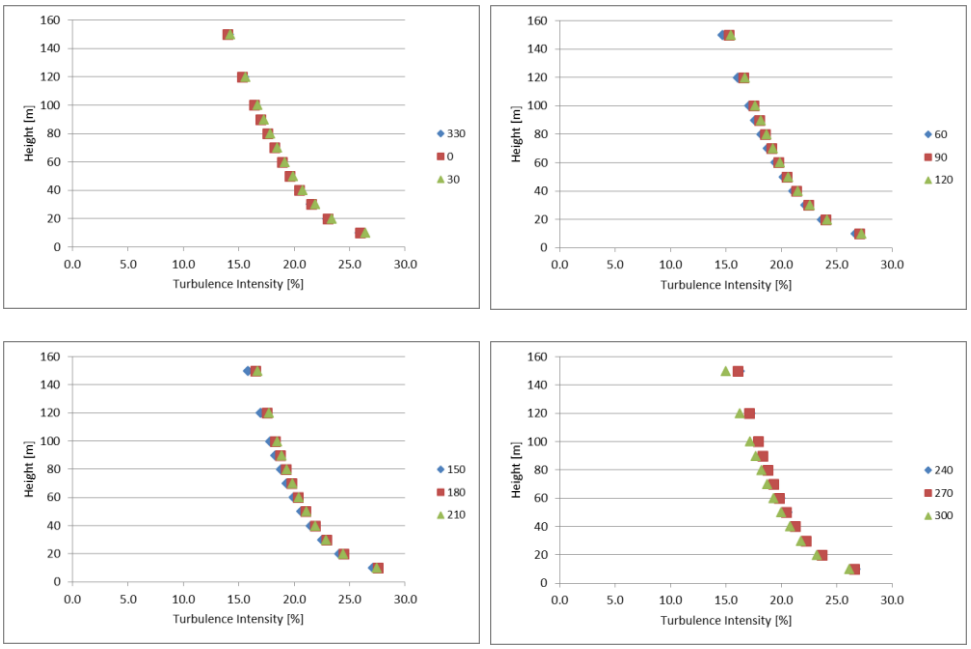
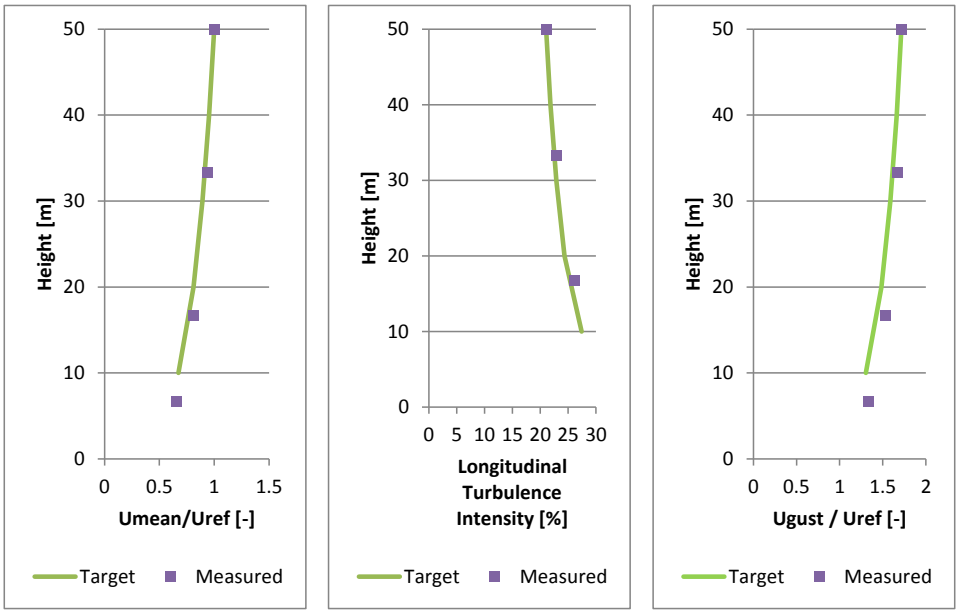


Figure A.4 presents the variation of mean wind speed, longitudinal turbulence intensity and gust wind speed used in the tests. The wind speed profiles are normalised by the mean wind speed at a reference height of 50m.

Figure A.4: Mean wind speed ($U_{mean}/U_{mean}(ref)$), longitudinal turbulence intensity profiles (I_u) and gust wind speed ($U_{gust}/U_{mean}(ref)$) modelled in the study



It can be seen that, over the range of heights of interest, the boundary layer simulations used in the tests were a good representation of the profiles expected for the site at full scale.

A.3. Wind Frequency Data

Wind microclimate studies require that wind speed data obtained from a measurement station be transposed to the site of interest.

The wind speed history, provided by weather centres such as the UK Met Office or the National Oceanic & Atmospheric Administration, is reformatted into the number of observations of mean hourly wind speeds within each of several wind speed ranges, for each wind direction and for each month of the year. To facilitate the transposition of the wind data, the months are grouped into the seasons and a Weibull distribution is fitted to the wind speed distribution for each wind direction, for each season.

From the Weibull cumulative distribution the probability that, for a given wind direction, a wind speed, V, will be exceeded is given by:

$$P(>V) = e^{-(\frac{V}{c})^k}$$

where c is the dispersion parameter and k is the shape parameter.

To these parameters is further added the probability, *p*, of each wind direction occurring. Thus for each month of the year the probability that a specified wind speed is exceeded for a specified wind direction may be calculated.

The resulting weather centre wind data is transposed to a standard reference terrain category, 'open country terrain', at sea-level, accounting for upwind terrain, topography and altitude for the weather centre.

The open country wind data is then transposed to reference height at the site of the proposed development, accounting for upwind terrain, topography and altitude for the target site. The resulting annual and seasonal directional and wind speed probability distributions at a reference height of 50m, at the proposed site, are given in Figures A.5a to A.5e, respectively.

Values of *p*, *c* and *k* for the London Heathrow Weather Centre, transposed to open-country terrain at 10m height above sea-level altitude are given in Table A.2.

Figure A.5a: Directional Windspeed Probability Distribution at Site: Annual (at 50m height)

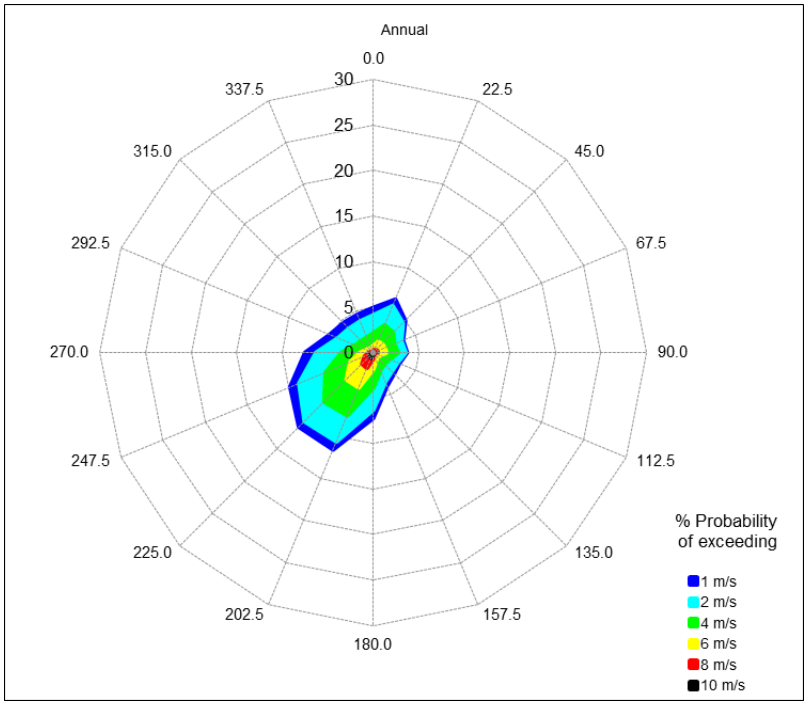


Figure A.5b: Directional Windspeed Probability Distribution at Site: Spring (at 50m height)

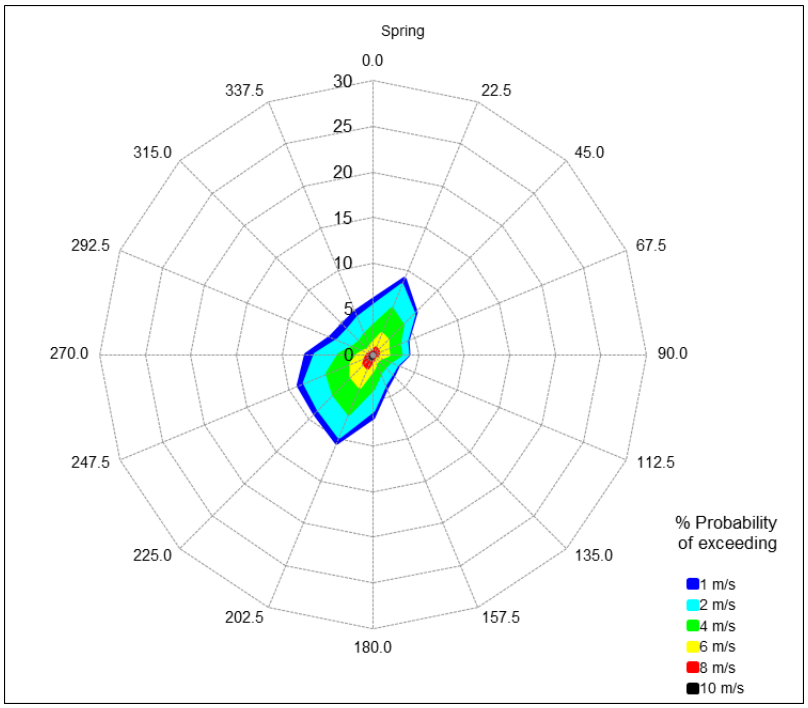


Figure A.5c: Directional Windspeed Probability Distribution at Site: Summer (at 50m height)

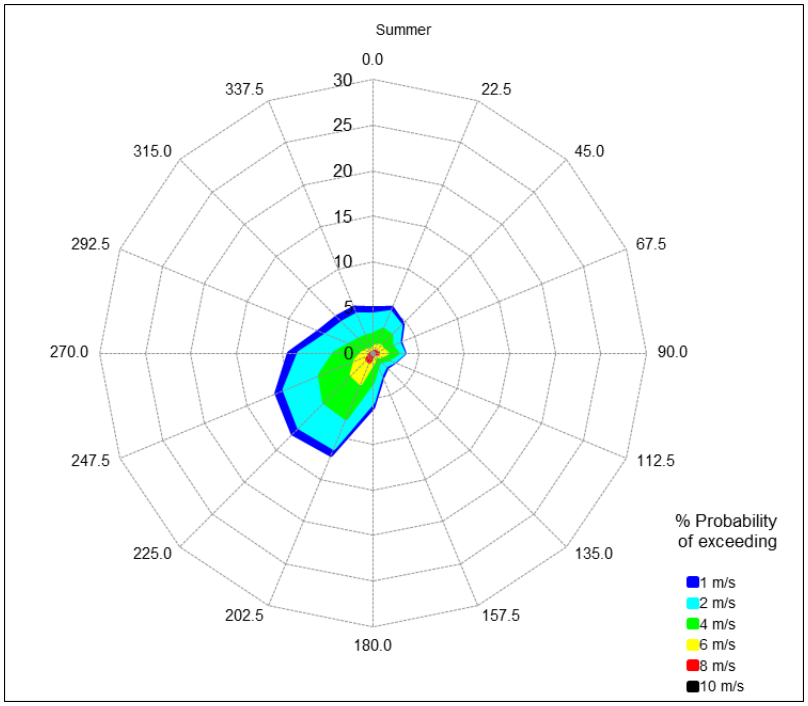


Figure A.5d: Directional Windspeed Probability Distribution at Site: Autumn (at 50m height)

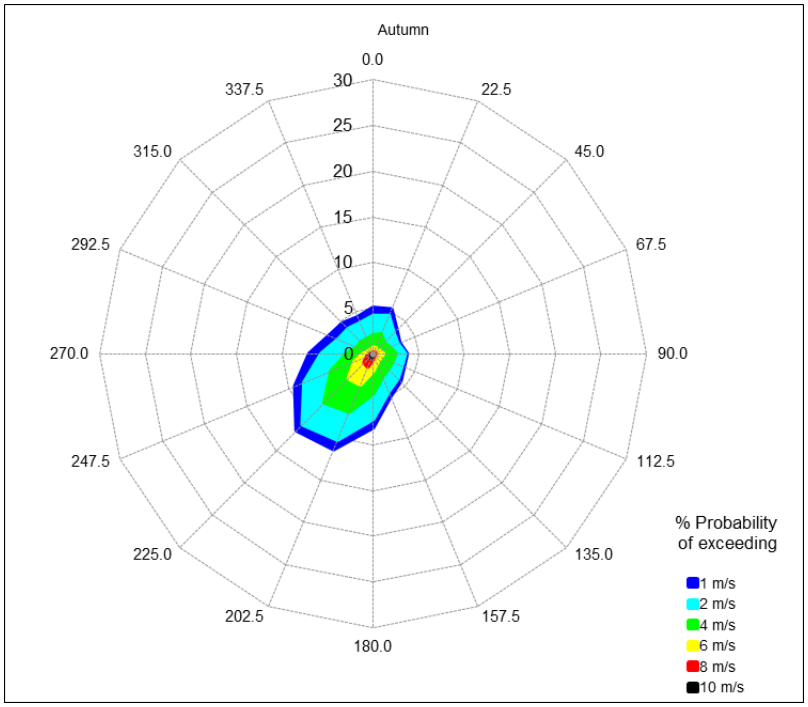


Figure A.5e: Directional Windspeed Probability Distribution at Site: Winter (at 50m height)

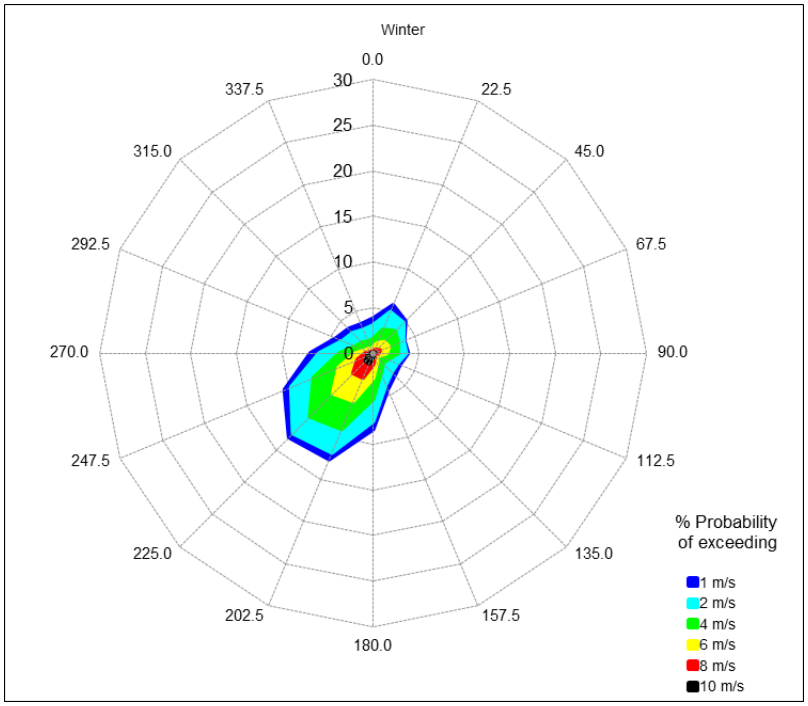


Table A.2: Wind frequency statistics: corrected London Heathrow weather centre data transformed to z0=0.03m Weibull Coefficients

Annual	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°
P	5.28	6.57	5.05	3.56	3.73	3.14	3.35	4.14	7.58	11.87	11.82	10.28	8.08	5.67	5.03	4.85
C	3.77	4.26	4.84	5.52	5.59	4.92	4.44	4.43	4.56	5.42	5.43	4.79	4.06	3.70	3.58	3.62
K	1.88	2.06	2.38	2.46	2.68	2.48	2.18	1.94	1.84	2.01	2.13	1.97	1.74	1.69	1.79	1.91

Autumn	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°
P	5.44	5.53	3.78	3.17	3.74	3.71	4.37	5.19	8.42	11.76	12.16	9.66	7.66	5.75	5.08	4.59
C	3.60	3.82	3.90	4.81	5.11	4.82	4.52	4.49	4.54	5.11	5.16	4.51	3.70	3.42	3.55	3.63
K	1.86	2.09	2.31	2.48	2.70	2.55	2.24	2.11	2.01	1.92	2.19	1.99	1.72	1.74	1.89	2.09

Winter	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°
P	4.27	6.06	5.06	3.71	3.87	3.29	3.57	4.52	8.74	12.86	13.22	10.77	7.37	4.79	4.10	3.79
C	3.56	4.12	5.25	6.22	5.59	4.51	4.00	4.54	5.10	6.10	6.25	5.58	4.59	3.96	3.82	3.59
K	1.60	1.85	2.47	2.74	2.42	2.19	1.96	1.76	1.82	2.06	2.29	2.06	1.65	1.60	1.76	1.70

Spring	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°
P	6.26	9.20	6.67	4.10	3.87	3.01	3.23	4.01	7.13	10.63	9.24	9.04	7.77	5.49	5.03	5.35
C	4.21	4.72	5.19	5.66	5.76	5.09	4.67	4.48	4.52	5.45	5.49	4.94	4.29	3.92	3.76	3.95
K	2.06	2.24	2.61	2.65	3.01	2.60	2.31	2.08	2.05	2.20	2.20	2.22	1.85	1.64	1.79	1.97

Summer	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°
P	5.12	5.49	4.66	3.25	3.45	2.56	2.24	2.88	6.07	12.26	12.72	11.67	9.52	6.64	5.85	5.62
C	3.69	4.17	4.65	5.20	5.84	5.27	4.50	4.17	4.33	5.07	4.87	4.43	4.01	3.76	3.57	3.51
K	2.27	2.49	2.55	2.45	2.87	2.78	2.15	2.15	2.40	2.43	2.35	2.57	2.34	2.19	2.27	2.35

APPENDIX B. WIND TUNNEL & MODEL DETAILS

B.1. Wind Tunnel Specifications

All the tests were conducted in BMT's Boundary Layer Wind Tunnel which has a working section 4.8m wide, 2.4m high and 15m long with a 4.4m diameter multiple plate turntable and a remotely controlled 3-dimensional traversing system. The operating wind speed range is 0.2 – 45 m/s.

A turbulent boundary layer, representative of the conditions at the site, is set up using an arrangement of roughness elements distributed over the floor of the wind tunnel and a 2-dimensional barrier with square posts or spires at the entrance to the test section.

B.2. Model

B.2.1. Information For Model Construction

The model of the proposed development was constructed based on drawing information supplied by Populous, the architects for the scheme, as follows:

Drawing	Date
150630_EIA THFC_.3dm	01/07/2015
THFC podium landscape.png	21/07/2015
podium landscape.jpg	21/07/2015
POP-4494-9243.dwg	25/08/2015
13_PUBLIC REALM 16.pdf	04/09/2015
POP-4494-PLN-GA-8000.pdf	04/09/2015

The model of the existing surrounding area was based on OS superplan data supplemented by a site survey conducted by BMT using publically available information.

B.2.2. Scale

A model scale of 1:200 has been adopted. At this scale the model is large enough to allow a good representation of the details that are likely to affect the local and overall wind flows at full scale. In addition, this scale enables a good simulation of the turbulence properties of the wind to be achieved.

B.2.3. Construction

The model was constructed from a combination of materials such as hard foam and wood. The model incorporated all of the features that are likely to significantly affect the local wind flow around the development at full scale. The surrounding area was modelled to a radius of 440m from the centre of the site. The surrounding buildings and topography were represented to a sufficient level of detail to reproduce the wind flows at the location of the proposed development.

The model was mounted on a 4.4m diameter baseboard and installed on the 4.4m diameter turntable of BMT's Boundary Layer Wind Tunnel.

B.2.4. Model Photos

Images of the wind tunnel model are presented as:

- Figure B.1 - Opening day scenario
- Figure B.2 - Completed podium
- Figure B.3 - Completed hotel
- Figure B.4 - Completed sports development
- Figure B.5 - Completed masterplan
- Figure B.6 - Health centre
- Figure B.7 - proximity model: existing surrounding conditions
- Figure B.8 - wind tunnel set-up, viewed from downstream

Figure B.1: Opening day scenario

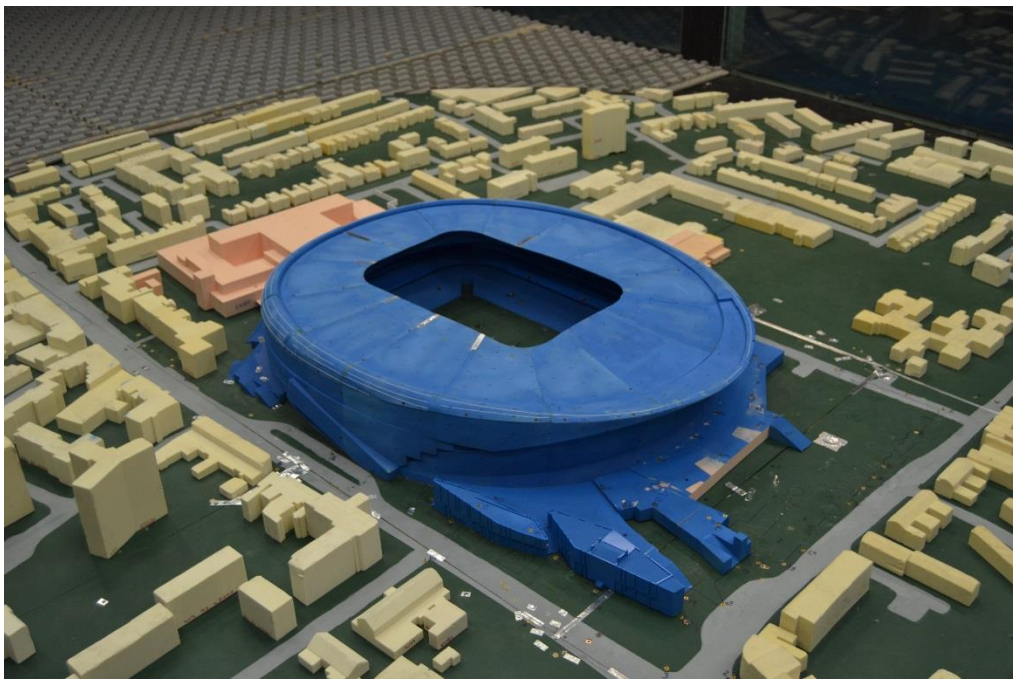


Figure B.2: Completed podium

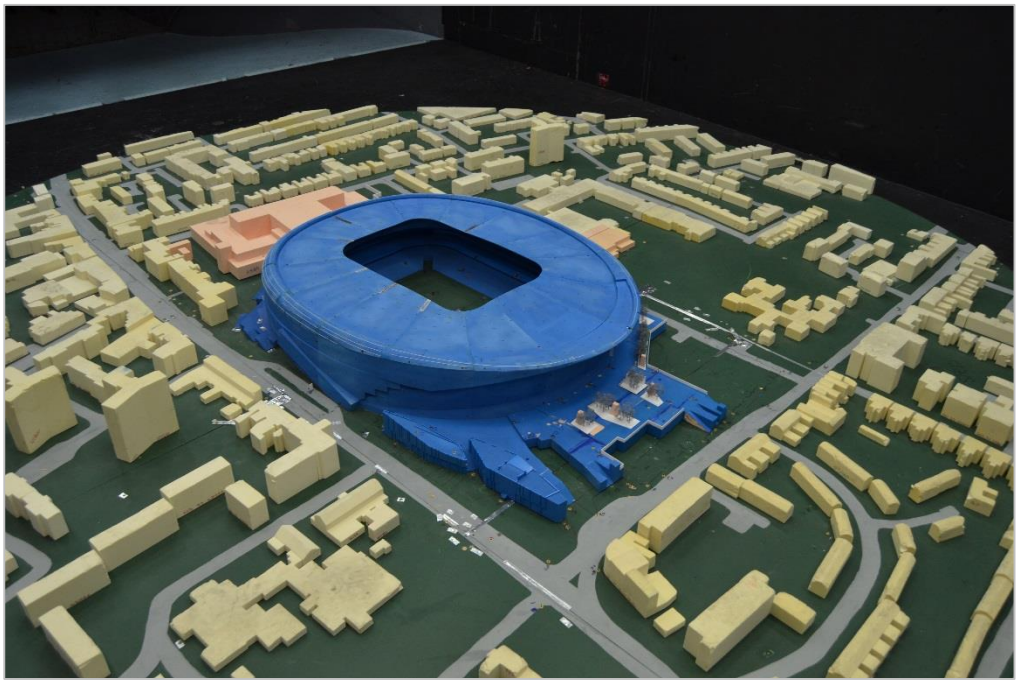


Figure B.3: Completed hotel

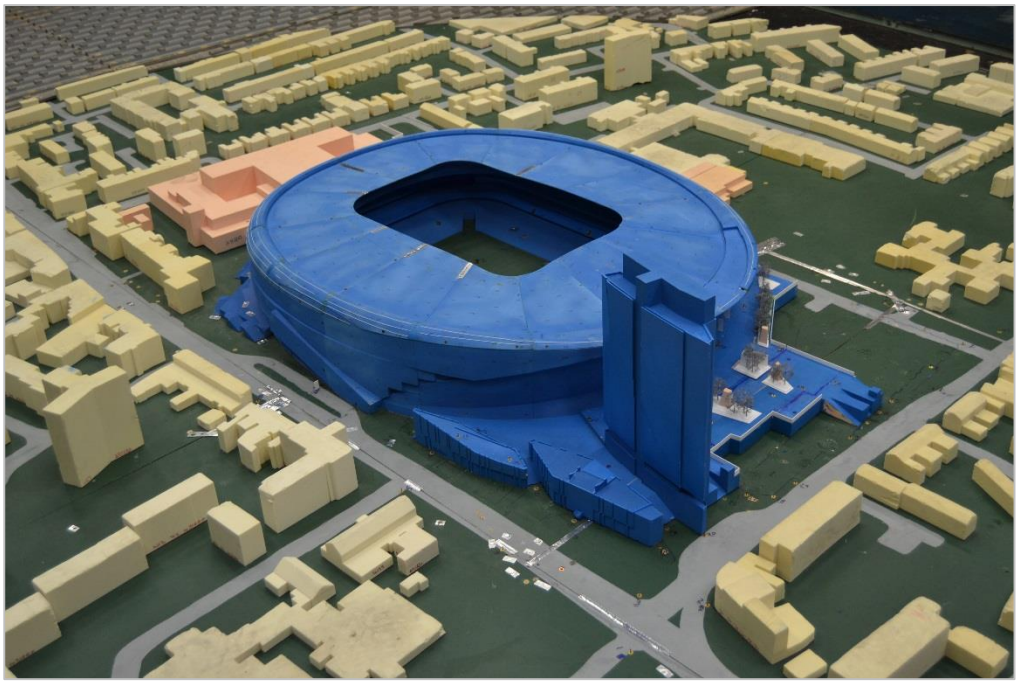


Figure B.4: Completed sports development

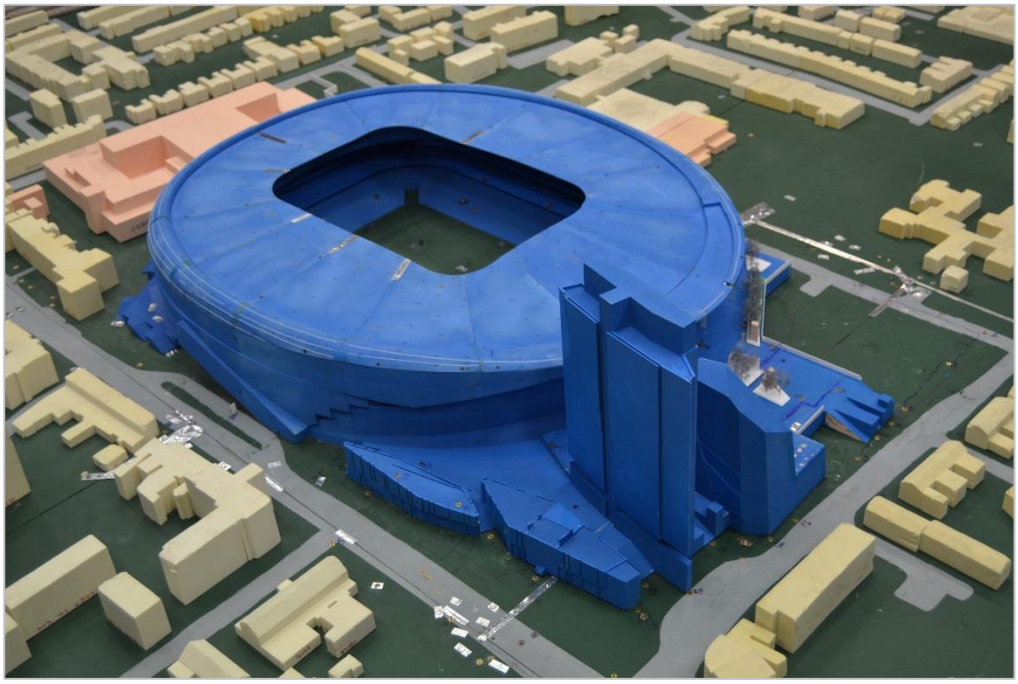


Figure B.5: Completed masterplan

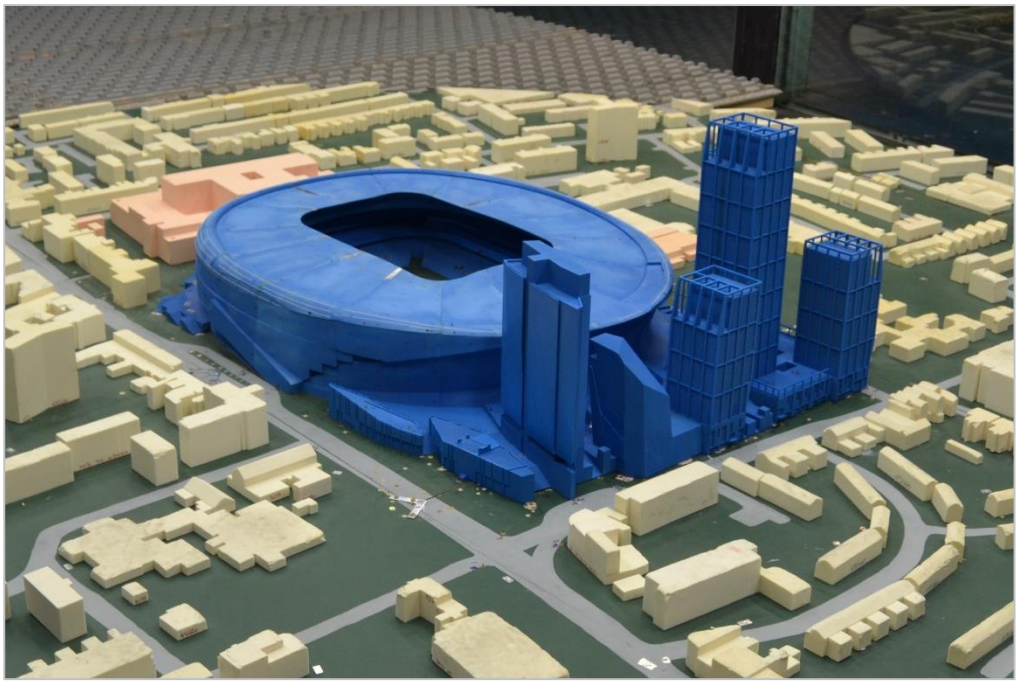


Figure B.6: Health centre

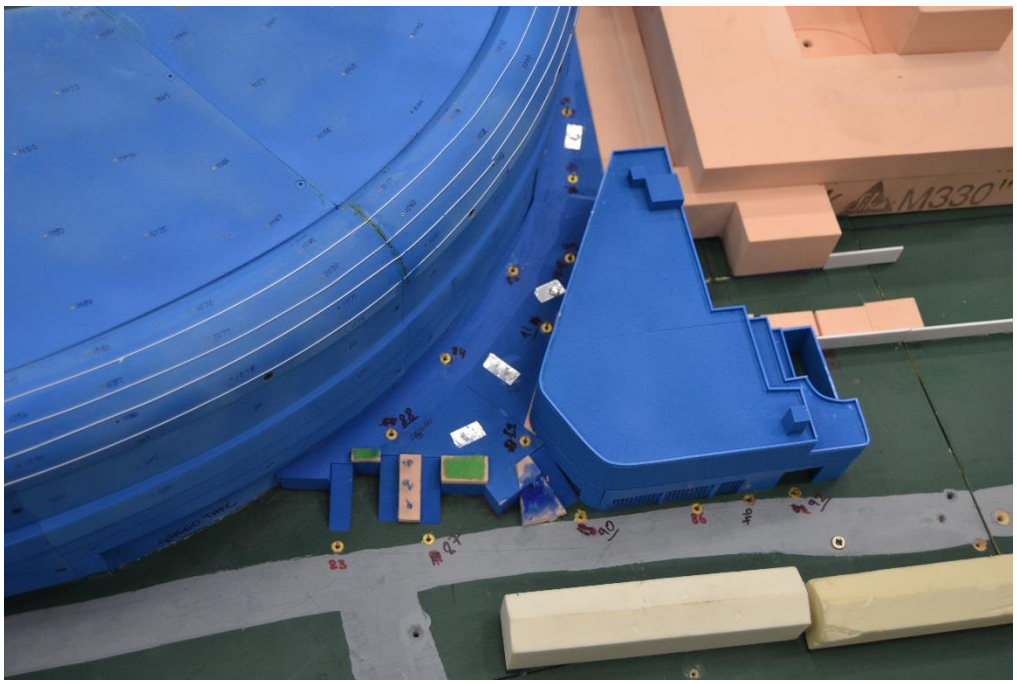


Figure B.7: proximity model: existing surrounding conditions

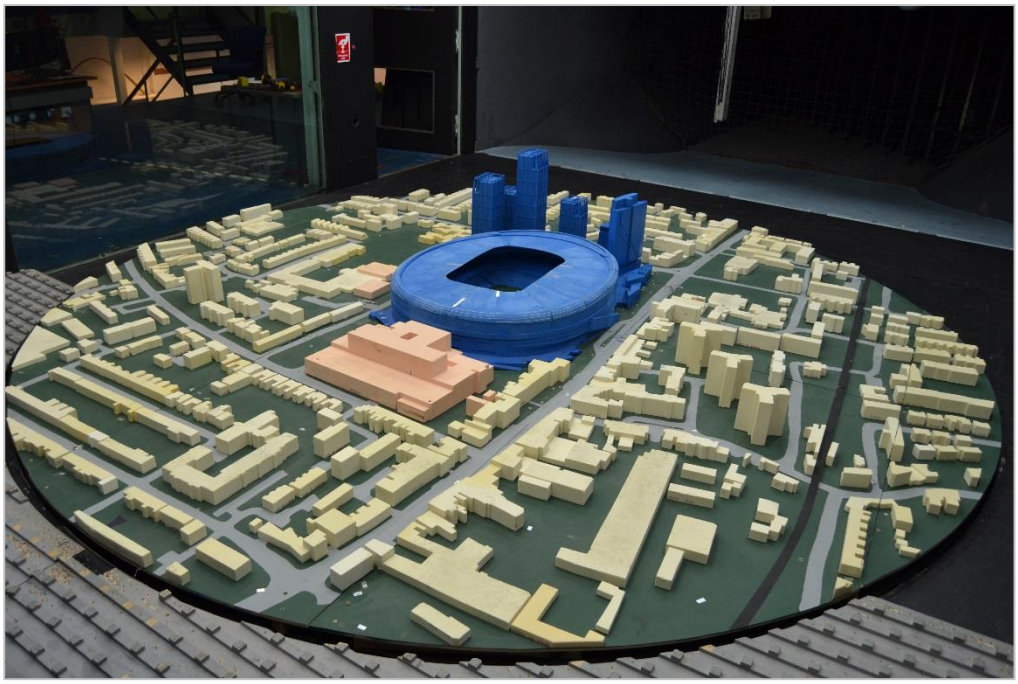
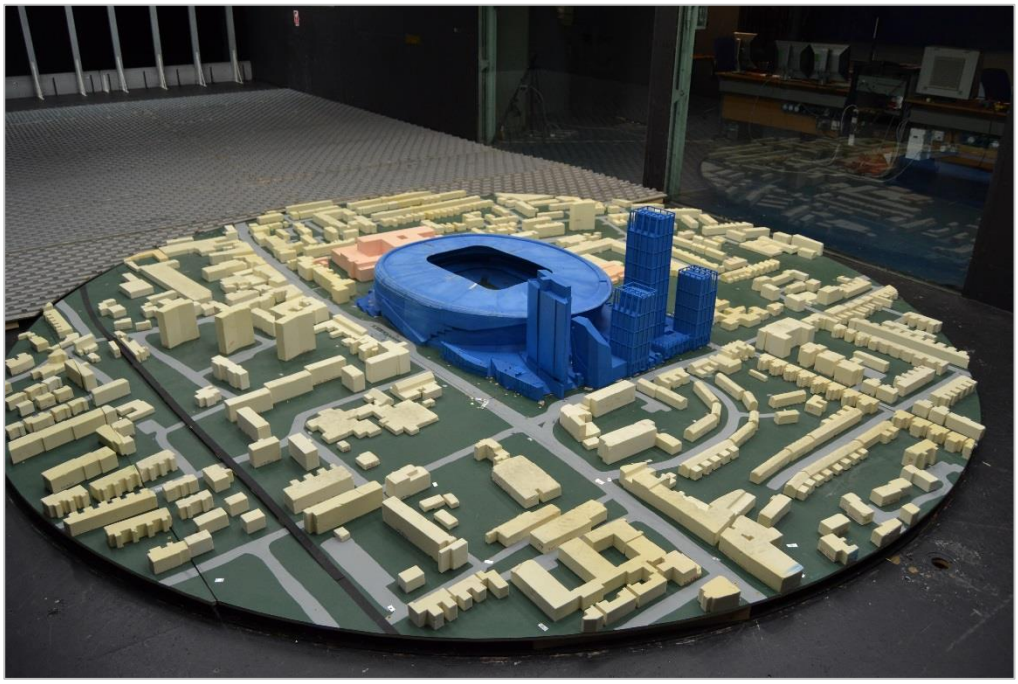


Figure B.8: Wind tunnel set-up, viewed from downstream



APPENDIX C. MEASUREMENTS AND ANALYSIS

C.1. Wind Speed Measurements

Wind speed measurements were made using so-called 'Irwin probes', capable of measuring fluctuating pressure differences that are calibrated against wind speed. A system of probes running simultaneously was used to obtain results from up to 99 locations at a height corresponding to 1.5m at full scale. Measurements were taken for a full range of wind directions in increments of 22.5°.

Data were recorded for a sufficient length of time to determine the mean and 3-second gust wind speeds.

Gusts in the wind flow may lead to additional discomfort beyond that caused by the mean wind speed. In order to assess this discomfort the gust wind speed is translated to an equivalent mean wind speed, the Gust Equivalent Mean or GEM, according to the following equation:

$$U_{GEM} = \frac{U_{GUST}}{1.85}$$

For each location the results were combined with local wind statistics to assess the wind microclimate in terms of the exceedance of threshold wind speeds that relate to comfort levels perceived during standard pedestrian activities.

C.2. Assessment Criteria

The accepted, UK industry standard, Lawson criteria for pedestrian comfort and safety are applied in the study. BMT adhere to the LDDC variant of the Lawson criteria[3].

Details of the comfort criteria are presented in Table C.1 and are based on the exceedance of the threshold wind speeds, based on the mean hourly value and on the gust equivalent mean value, occurring less than 5% of the time. The value of 5% has been established as giving a reasonable allowance for extreme and relatively infrequent winds that are tolerable within each category.

Table C.1: Lawson comfort criteria – LDDC variant[3]

Threshold Wind Speed	Comfort Rating / Activity		Examples
4 m/s	C4	Long-term standing / sitting	Reading a newspaper and eating and drinking
6 m/s	C3	Short-term standing / sitting	Appropriate for bus stops, window shopping and building entrances
8 m/s	C2	Leisure thoroughfare / strolling	General areas of walking and sightseeing
10 m/s	C1	Pedestrian transit / thoroughfare (A-B)	Local areas around tall buildings where people are not likely to linger
> 10 m/s	C0	Uncomfortable for all uses	Uncomfortable for all pedestrian activities

Details of the safety criteria are presented in Table C.2 and are based on the exceedance of threshold wind speeds, again both the mean-hourly value and on the gust equivalent mean value, occurring once per annum.

- A wind speed greater than 15 metres-per-second occurring once a year is classified as unsuitable for general public and represents a wind speed with the potential to destabilise the less able members of the public such as the elderly, cyclists and children.
- Able-bodied users are those determined to experience distress when the wind speed exceeds 20 metres-per-second once per year.

Table C.2: Lawson safety criteria – LDDC variant[3]

Threshold Wind Speed	Safety Rating		Qualifying Comments
> 15 m/s	S2	Unsuitable for general public	Less able and cyclists find conditions physically difficult
> 20 m/s	S1	Unsuitable for able-bodied	Able-bodied persons find conditions difficult. Physically impossible to remain standing during gusts.

C.3. Pedestrian Activities

Tables C.3a to C.3c present the pedestrian uses assumed for each of the corresponding measurement locations presented in Figures 6.1 to 6.7.

- Table C.3a presents the pedestrian uses for the opening day scenario
- Table C.3b presents the pedestrian uses for the completed podium and completed hotel construction phases
- Table C.3c presents the pedestrian uses for the completed sports development construction phase and completed masterplan

Table C.3a: Pedestrian uses, opening day scenario

Loc'n	Intended Use	Loc'n	Intended Use
1	Leisure Thoroughfare	45	Leisure Thoroughfare
2	Leisure Thoroughfare	46	Leisure Thoroughfare
3	Leisure Thoroughfare	47	Leisure Thoroughfare
4	Leisure Thoroughfare	48	Leisure Thoroughfare
5	Leisure Thoroughfare	49	Leisure Thoroughfare
6	Leisure Thoroughfare	50	Leisure Thoroughfare
7	Leisure Thoroughfare	51	Entrance / Shop Front / Waiting Area
8	Entrance / Shop Front / Waiting Area	52	Leisure Thoroughfare
9	Leisure Thoroughfare	53	Entrance / Shop Front / Waiting Area
10	Leisure Thoroughfare	54	Entrance / Shop Front / Waiting Area
11	Leisure Thoroughfare	55	Leisure Thoroughfare
12	Leisure Thoroughfare	56	Leisure Thoroughfare
13	Entrance / Shop Front / Waiting Area	57	Leisure Thoroughfare
14	Entrance / Shop Front / Waiting Area	58	Thoroughfare (A-to-B)
15	Leisure Thoroughfare	59	Entrance / Shop Front / Waiting Area
16	Recreational Space	67	Outdoor Seating
17	Recreational Space	68	Recreational Space
18	Leisure Thoroughfare	70	Leisure Thoroughfare
19	Leisure Thoroughfare	73	Leisure Thoroughfare
20	Leisure Thoroughfare	74	Leisure Thoroughfare
21	Leisure Thoroughfare	75	Recreational Space
22	Leisure Thoroughfare	76	Leisure Thoroughfare
23	Recreational Space	77	Leisure Thoroughfare
24	Recreational Space	78	Entrance / Shop Front / Waiting Area
25	Leisure Thoroughfare	79	Entrance / Shop Front / Waiting Area
26	Entrance / Shop Front / Waiting Area	80	Entrance / Shop Front / Waiting Area
27	Leisure Thoroughfare	81	Leisure Thoroughfare
28	Leisure Thoroughfare	82	Entrance / Shop Front / Waiting Area
29	Leisure Thoroughfare	83	Leisure Thoroughfare
30	Leisure Thoroughfare	84	Entrance / Shop Front / Waiting Area

34	Leisure Thoroughfare	85	Entrance / Shop Front / Waiting Area
35	Leisure Thoroughfare	86	Leisure Thoroughfare
36	Leisure Thoroughfare	87	Leisure Thoroughfare
37	Leisure Thoroughfare	88	Leisure Thoroughfare
38	Leisure Thoroughfare	89	Leisure Thoroughfare
39	Leisure Thoroughfare	90	Leisure Thoroughfare
40	Thoroughfare (A-to-B)	91	Recreational Space
41	Leisure Thoroughfare	92	Leisure Thoroughfare
42	Leisure Thoroughfare	93	Leisure Thoroughfare
43	Entrance / Shop Front / Waiting Area	94	Entrance / Shop Front / Waiting Area
44	Leisure Thoroughfare	95	Entrance / Shop Front / Waiting Area

Table C.3b: Pedestrian uses, completed podium and completed hotel construction phases

Loc'n	Intended Use	Loc'n	Intended Use
1	Leisure Thoroughfare	51	Entrance / Shop Front / Waiting Area
2	Leisure Thoroughfare	52	Recreational Space
3	Leisure Thoroughfare	53	Entrance / Shop Front / Waiting Area
4	Leisure Thoroughfare	54	Entrance / Shop Front / Waiting Area
5	Leisure Thoroughfare	55	Recreational Space
6	Leisure Thoroughfare	56	Leisure Thoroughfare
7	Leisure Thoroughfare	57	Leisure Thoroughfare
8	Entrance / Shop Front / Waiting Area	58	Thoroughfare (A-to-B)
9	Leisure Thoroughfare	59	Entrance / Shop Front / Waiting Area
10	Leisure Thoroughfare	60	Recreational Space
11	Leisure Thoroughfare	61	Recreational Space
12	Leisure Thoroughfare	62	Recreational Space
13	Entrance / Shop Front / Waiting Area	63	Recreational Space
14	Entrance / Shop Front / Waiting Area	64	Recreational Space
15	Leisure Thoroughfare	65	Recreational Space
16	Recreational Space	66	Recreational Space
17	Recreational Space	67	Outdoor Seating
18	Leisure Thoroughfare	68	Recreational Space
19	Leisure Thoroughfare	69	Recreational Space
20	Leisure Thoroughfare	70	Leisure Thoroughfare
21	Leisure Thoroughfare	71	Thoroughfare (A-to-B)
22	Recreational Space	72	Leisure Thoroughfare
23	Recreational Space	73	Leisure Thoroughfare
24	Recreational Space	74	Leisure Thoroughfare
25	Leisure Thoroughfare	75	Recreational Space
26	Entrance / Shop Front / Waiting Area	76	Leisure Thoroughfare

27	Leisure Thoroughfare	77	Leisure Thoroughfare
28	Leisure Thoroughfare	78	Entrance / Shop Front / Waiting Area
29	Leisure Thoroughfare	79	Entrance / Shop Front / Waiting Area
30	Leisure Thoroughfare	80	Entrance / Shop Front / Waiting Area
31	Recreational Space	81	Leisure Thoroughfare
32	Recreational Space	82	Entrance / Shop Front / Waiting Area
33	Leisure Thoroughfare	83	Leisure Thoroughfare
34	Leisure Thoroughfare	84	Entrance / Shop Front / Waiting Area
35	Leisure Thoroughfare	85	Entrance / Shop Front / Waiting Area
36	Leisure Thoroughfare	86	Leisure Thoroughfare
37	Leisure Thoroughfare	87	Leisure Thoroughfare
38	Leisure Thoroughfare	88	Leisure Thoroughfare
39	Leisure Thoroughfare	89	Leisure Thoroughfare
40	Thoroughfare (A-to-B)	90	Leisure Thoroughfare
41	Leisure Thoroughfare	91	Recreational Space
42	Leisure Thoroughfare	92	Leisure Thoroughfare
43	Entrance / Shop Front / Waiting Area	93	Leisure Thoroughfare
44	Leisure Thoroughfare	94	Entrance / Shop Front / Waiting Area
45	Leisure Thoroughfare	95	Entrance / Shop Front / Waiting Area
46	Leisure Thoroughfare	101	Outdoor Seating
47	Leisure Thoroughfare	102	Outdoor Seating
48	Leisure Thoroughfare	103	Outdoor Seating
49	Leisure Thoroughfare	104	Outdoor Seating
50	Leisure Thoroughfare		

Table C.3b: Pedestrian uses, completed sports development construction phase & completed masterplan

Loc'n	Intended Use	Loc'n	Intended Use
1	Leisure Thoroughfare	51	Entrance / Shop Front / Waiting Area
2	Leisure Thoroughfare	52	Recreational Space
3	Leisure Thoroughfare	53	Entrance / Shop Front / Waiting Area
4	Leisure Thoroughfare	54	Entrance / Shop Front / Waiting Area
5	Leisure Thoroughfare	55	Recreational Space
6	Leisure Thoroughfare	56	Leisure Thoroughfare
7	Leisure Thoroughfare	57	Leisure Thoroughfare
8	Entrance / Shop Front / Waiting Area	58	Thoroughfare (A-to-B)
9	Leisure Thoroughfare	59	Entrance / Shop Front / Waiting Area
10	Leisure Thoroughfare	60	Recreational Space
11	Leisure Thoroughfare	61	Recreational Space
12	Leisure Thoroughfare	62	Recreational Space
13	Entrance / Shop Front / Waiting Area	63	Recreational Space
14	Entrance / Shop Front / Waiting Area	64	Recreational Space

15	Leisure Thoroughfare	65	Recreational Space
16	Recreational Space	66	Recreational Space
17	Recreational Space	67	Outdoor Seating
18	Leisure Thoroughfare	68	Recreational Space
19	Leisure Thoroughfare	69	Recreational Space
20	Leisure Thoroughfare	70	Leisure Thoroughfare
21	Leisure Thoroughfare	71	Thoroughfare (A-to-B)
22	Recreational Space	72	Leisure Thoroughfare
23	Recreational Space	73	Leisure Thoroughfare
24	Recreational Space	74	Leisure Thoroughfare
25	Leisure Thoroughfare	75	Recreational Space
26	Entrance / Shop Front / Waiting Area	76	Leisure Thoroughfare
27	Entrance / Shop Front / Waiting Area	77	Leisure Thoroughfare
28	Leisure Thoroughfare	78	Entrance / Shop Front / Waiting Area
29	Entrance / Shop Front / Waiting Area	79	Entrance / Shop Front / Waiting Area
30	Leisure Thoroughfare	80	Entrance / Shop Front / Waiting Area
31	Recreational Space	81	Leisure Thoroughfare
32	Recreational Space	82	Entrance / Shop Front / Waiting Area
33	Leisure Thoroughfare	83	Leisure Thoroughfare
34	Leisure Thoroughfare	84	Entrance / Shop Front / Waiting Area
35	Leisure Thoroughfare	85	Entrance / Shop Front / Waiting Area
36	Leisure Thoroughfare	86	Leisure Thoroughfare
37	Leisure Thoroughfare	87	Leisure Thoroughfare
38	Leisure Thoroughfare	88	Leisure Thoroughfare
39	Leisure Thoroughfare	89	Leisure Thoroughfare
40	Thoroughfare (A-to-B)	90	Leisure Thoroughfare
41	Leisure Thoroughfare	91	Recreational Space
42	Leisure Thoroughfare	92	Leisure Thoroughfare
43	Entrance / Shop Front / Waiting Area	93	Leisure Thoroughfare
44	Leisure Thoroughfare	94	Entrance / Shop Front / Waiting Area
45	Leisure Thoroughfare	95	Entrance / Shop Front / Waiting Area
46	Leisure Thoroughfare	101	Outdoor Seating
47	Leisure Thoroughfare	102	Outdoor Seating
48	Leisure Thoroughfare	103	Outdoor Seating
49	Leisure Thoroughfare	104	Outdoor Seating
50	Leisure Thoroughfare		

APPENDIX D. COMFORT AND SAFETY RATINGS

The results of the wind speed measurements are summarised in graphical format in terms of comfort and safety ratings derived for each measurement location, as follows:

- Figures D.1a to D.1l presents **annual safety** ratings for each configuration, for ground, podium and rooftop terrace levels
- Figures D.2a to D.2l presents **summer season comfort** ratings for each configuration, for ground, podium and rooftop terrace levels
- Figures D.3a to D.3l presents **worst seasonal comfort** ratings for each configuration, for ground, podium and rooftop terrace levels

The presentations listed above show the worst case between the results derived using wind speed-up factors based on the mean and gust equivalent mean (GEM) wind speeds (see Appendix C).

Figure D.1a: Annual safety ratings, the opening day scenario, southern podium area

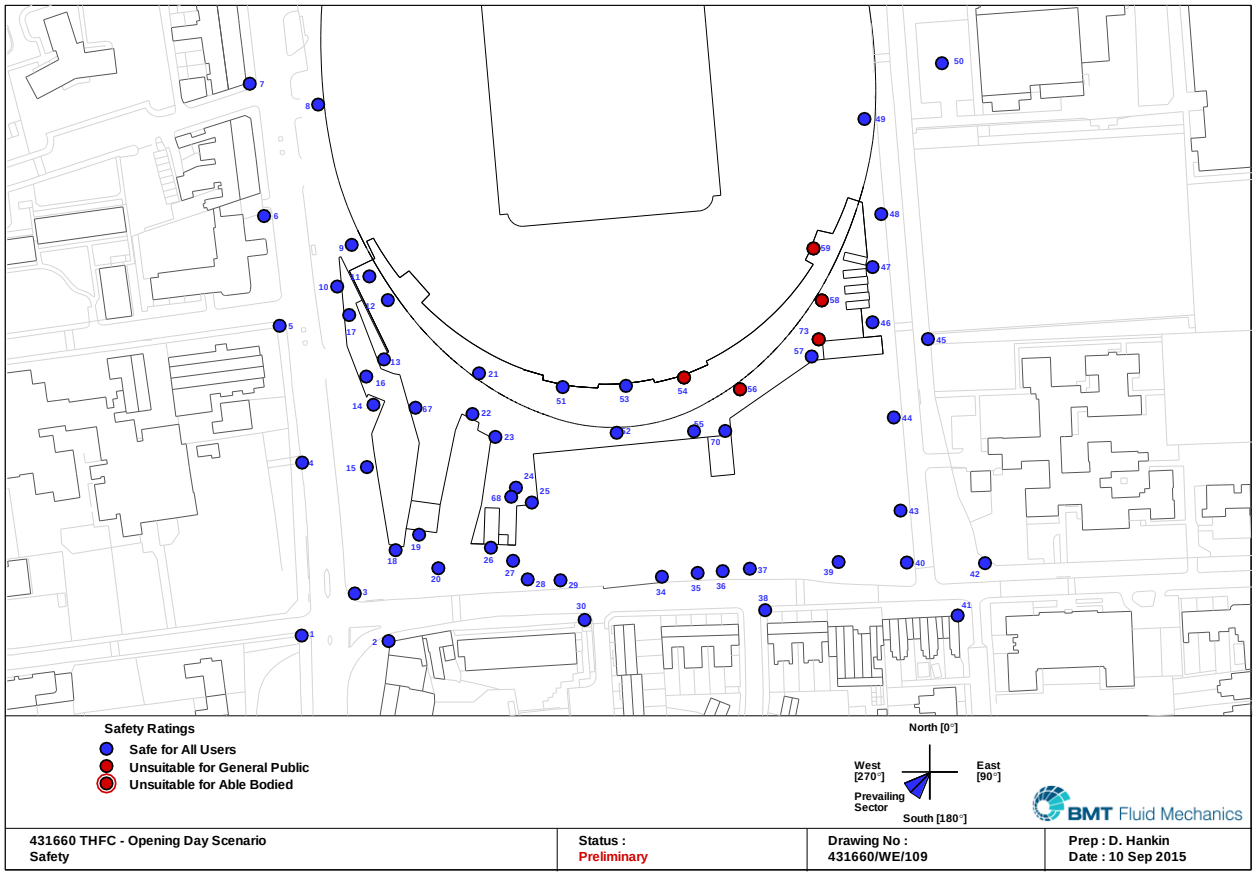


Figure D.1b: Annual safety ratings, the opening day scenario, northern podium area

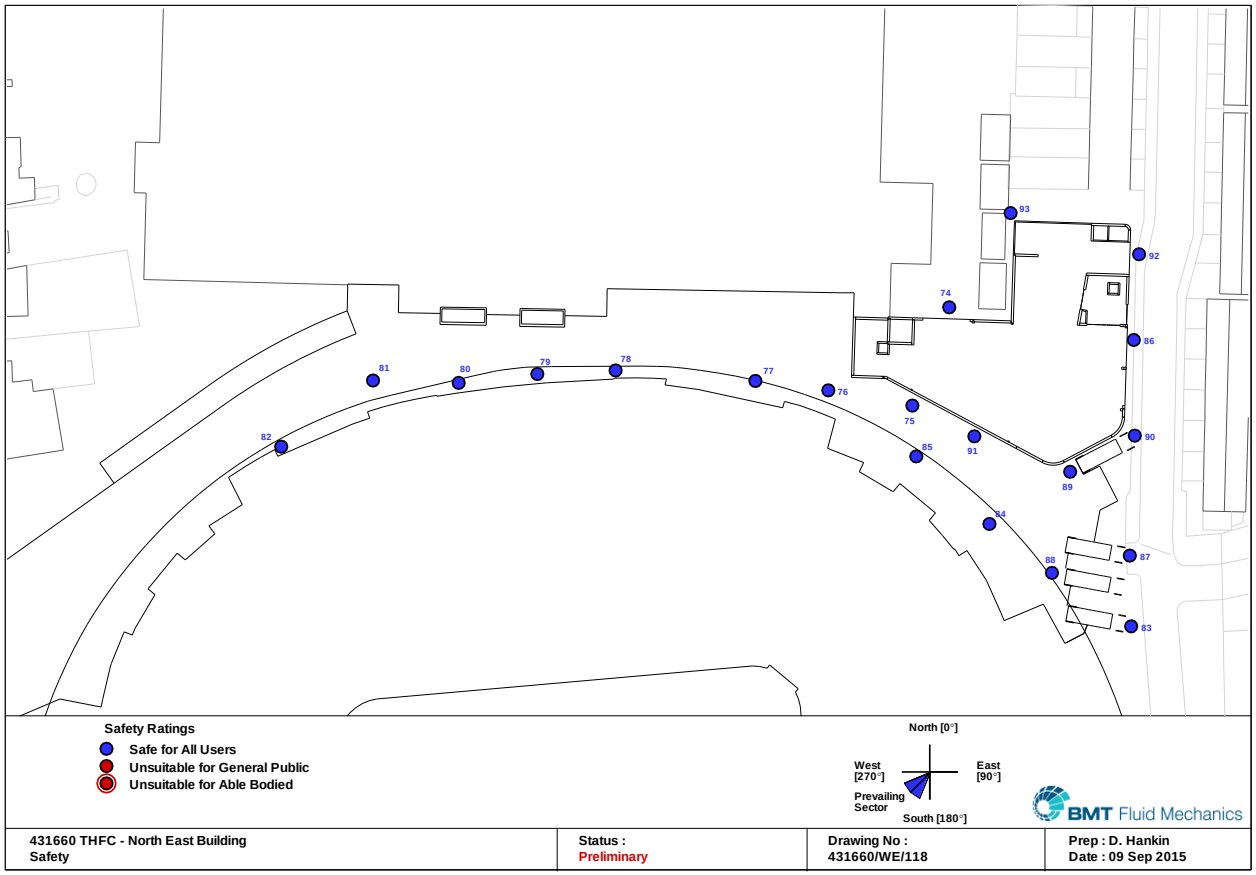


Figure D.1c: Annual safety ratings, the opening day scenario, southern podium area, with soft landscaping and wind mitigation

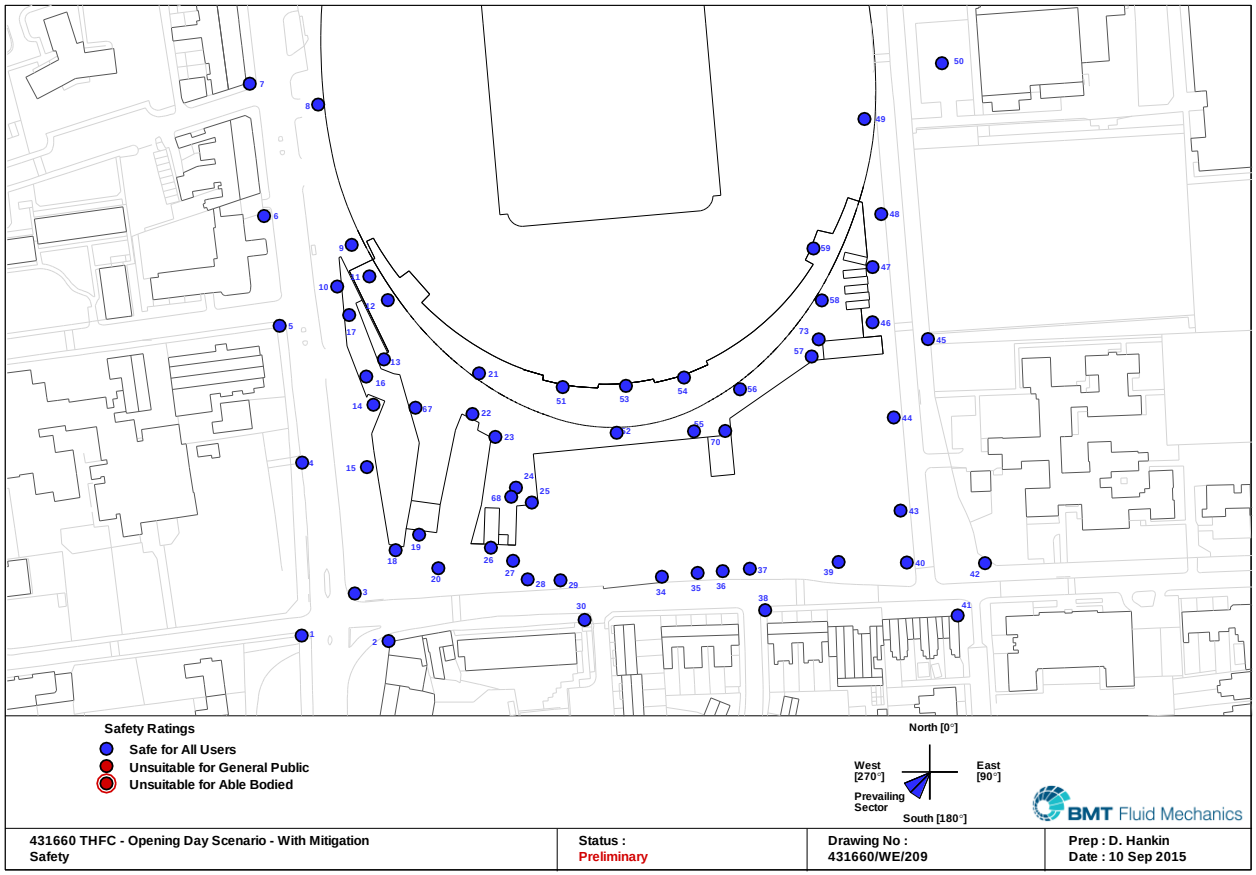


Figure D.1d: Annual safety ratings, the opening day scenario, northern podium area, with soft landscaping and wind mitigation

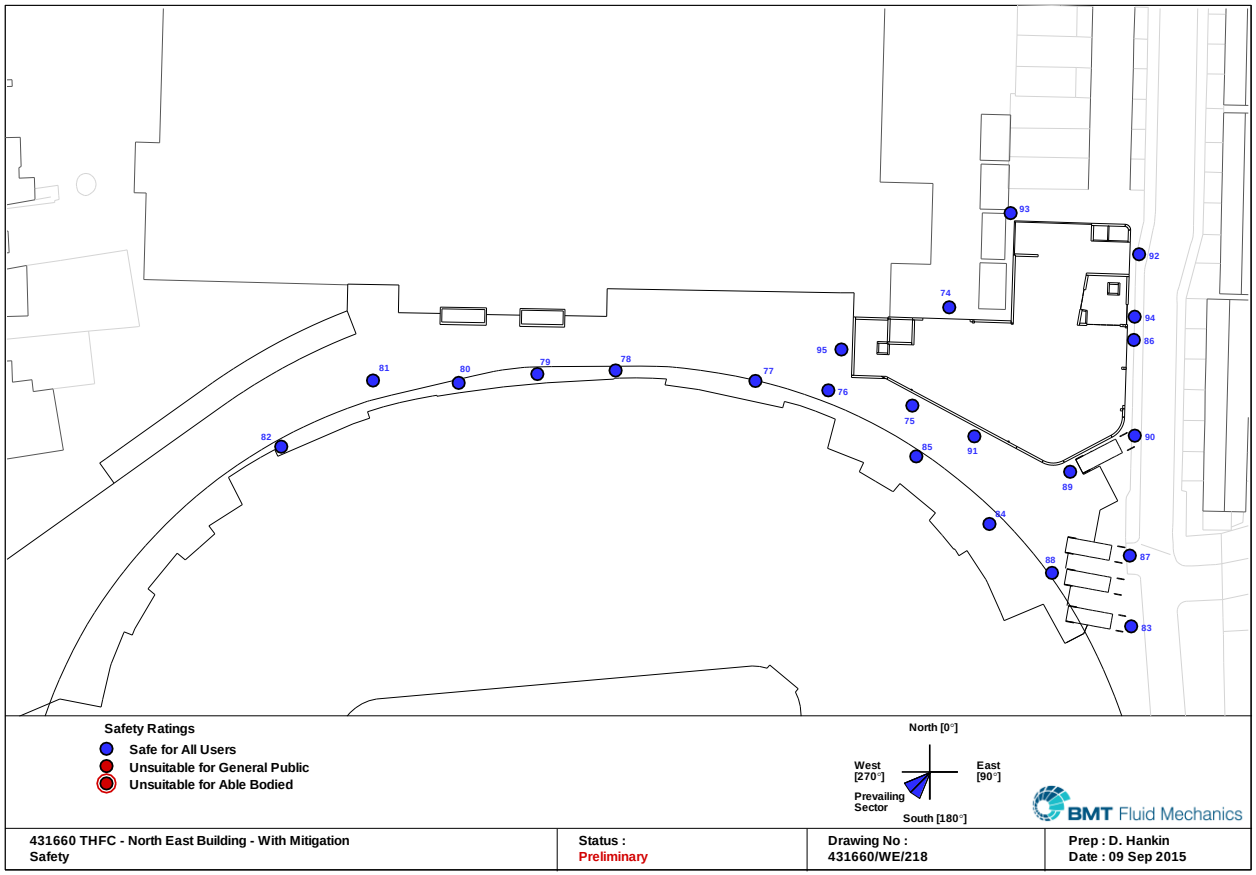


Figure D.1e: Annual safety ratings, the completed podium, southern podium area, with soft landscaping and wind mitigation

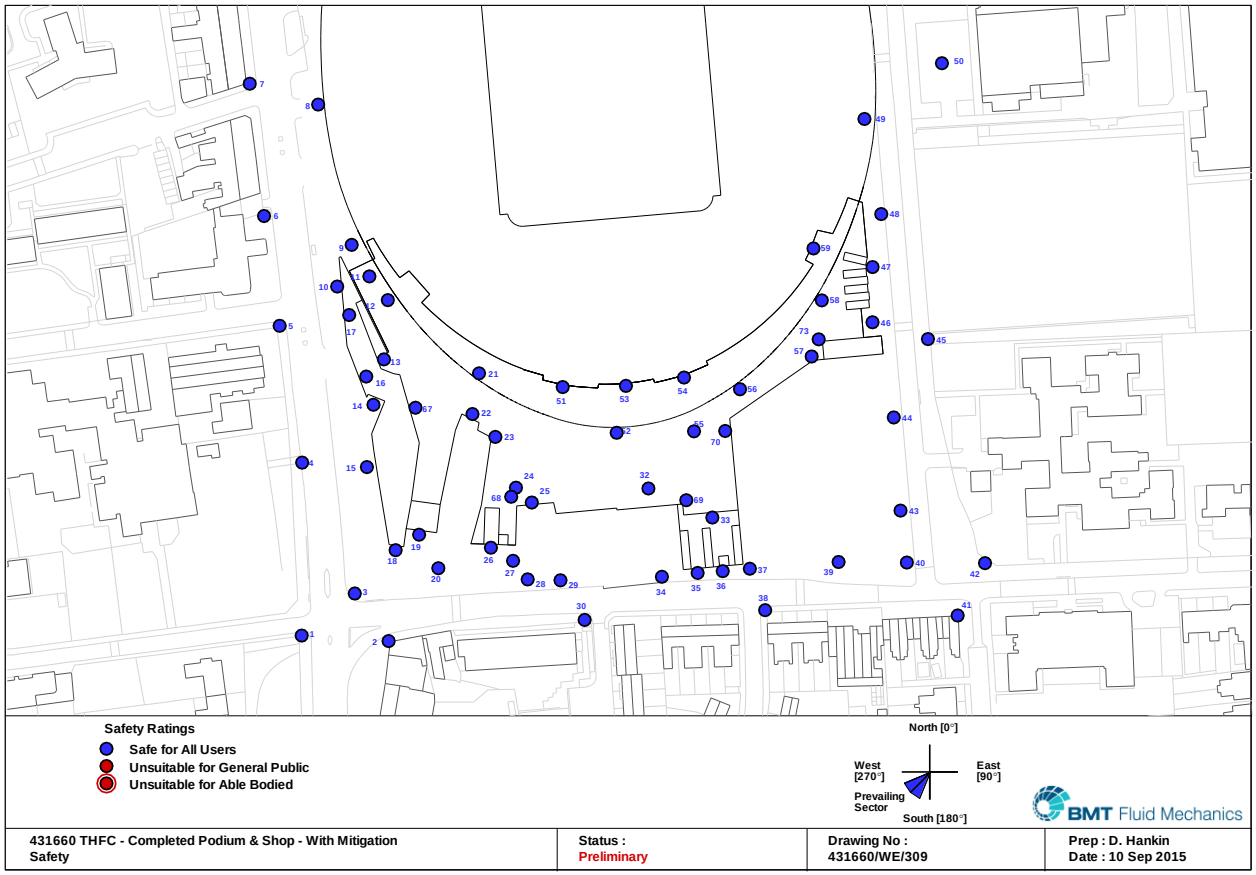


Figure D.1f: Annual safety ratings, the completed podium, northern podium area, with soft landscaping and wind mitigation

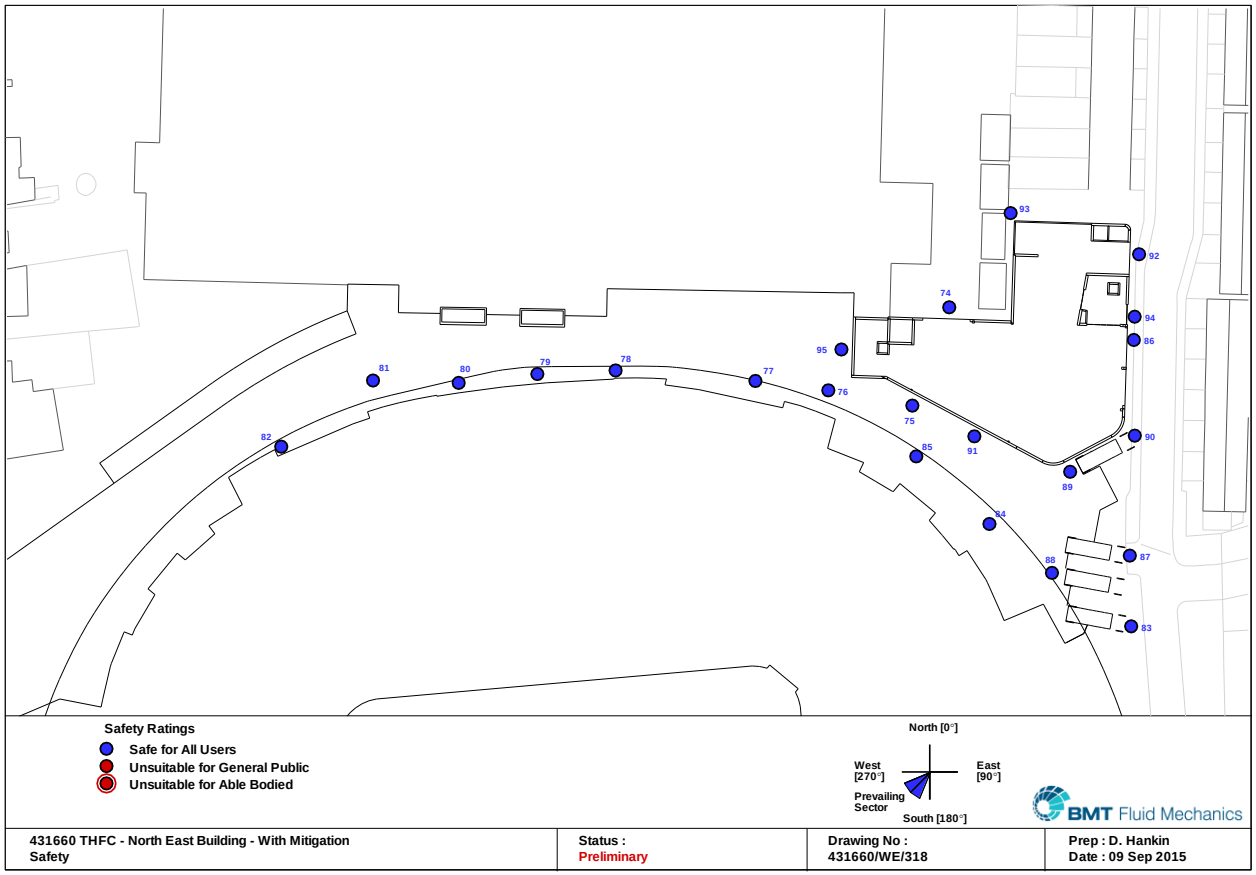


Figure D.1g: Annual safety ratings, the completed hotel, southern podium area, with soft landscaping and wind mitigation

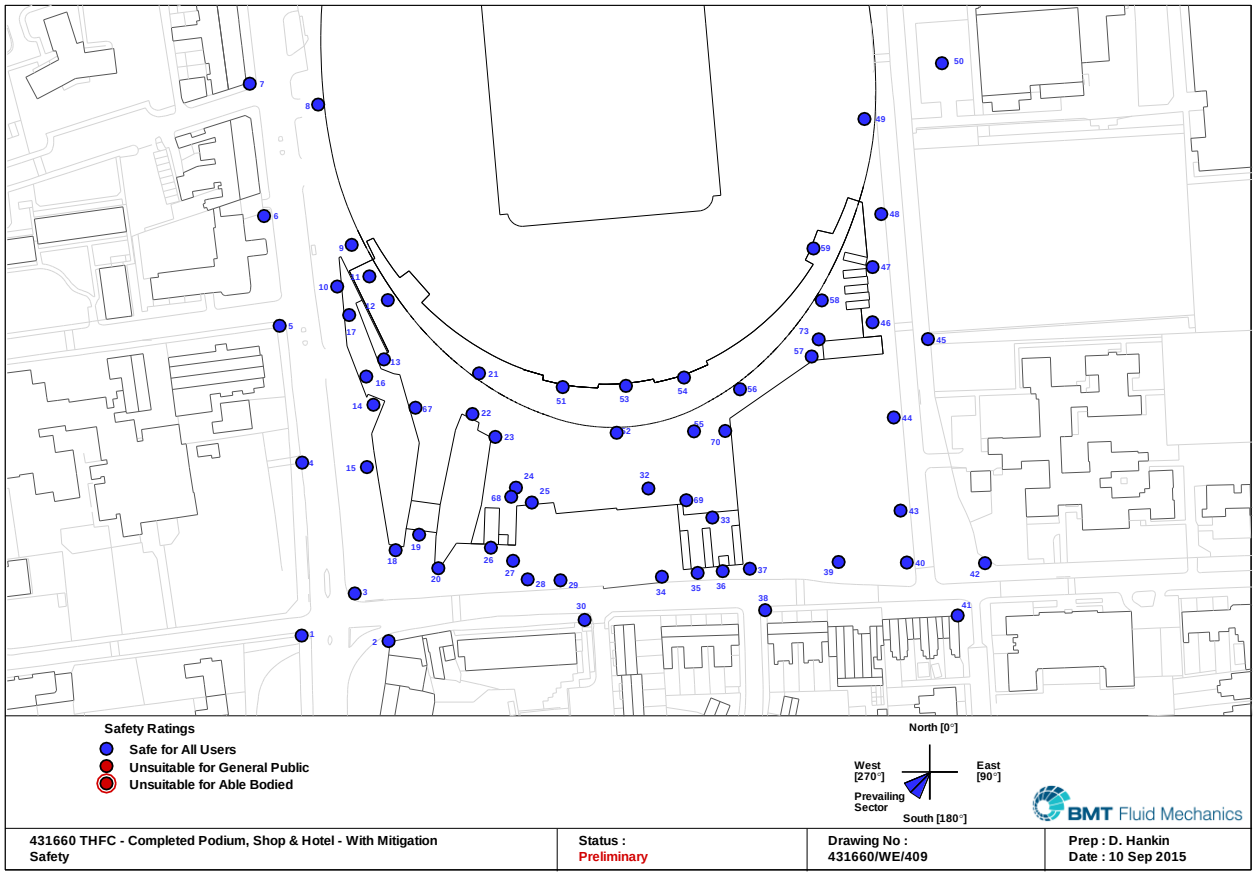


Figure D.1h: Annual safety ratings, the completed hotel, northern podium area, with soft landscaping and wind mitigation

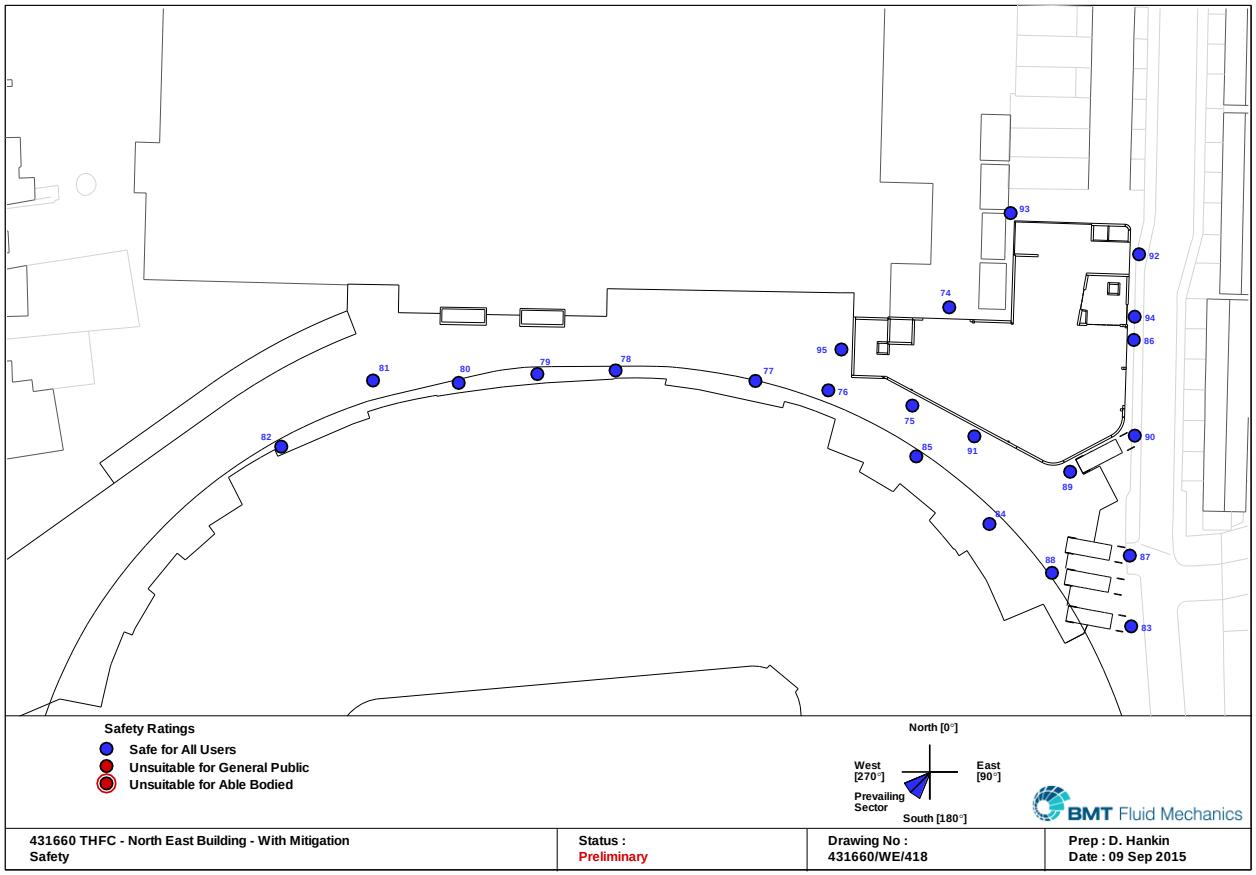


Figure D.1i: Annual safety ratings, the completed sports development, southern podium area, with soft landscaping and wind mitigation

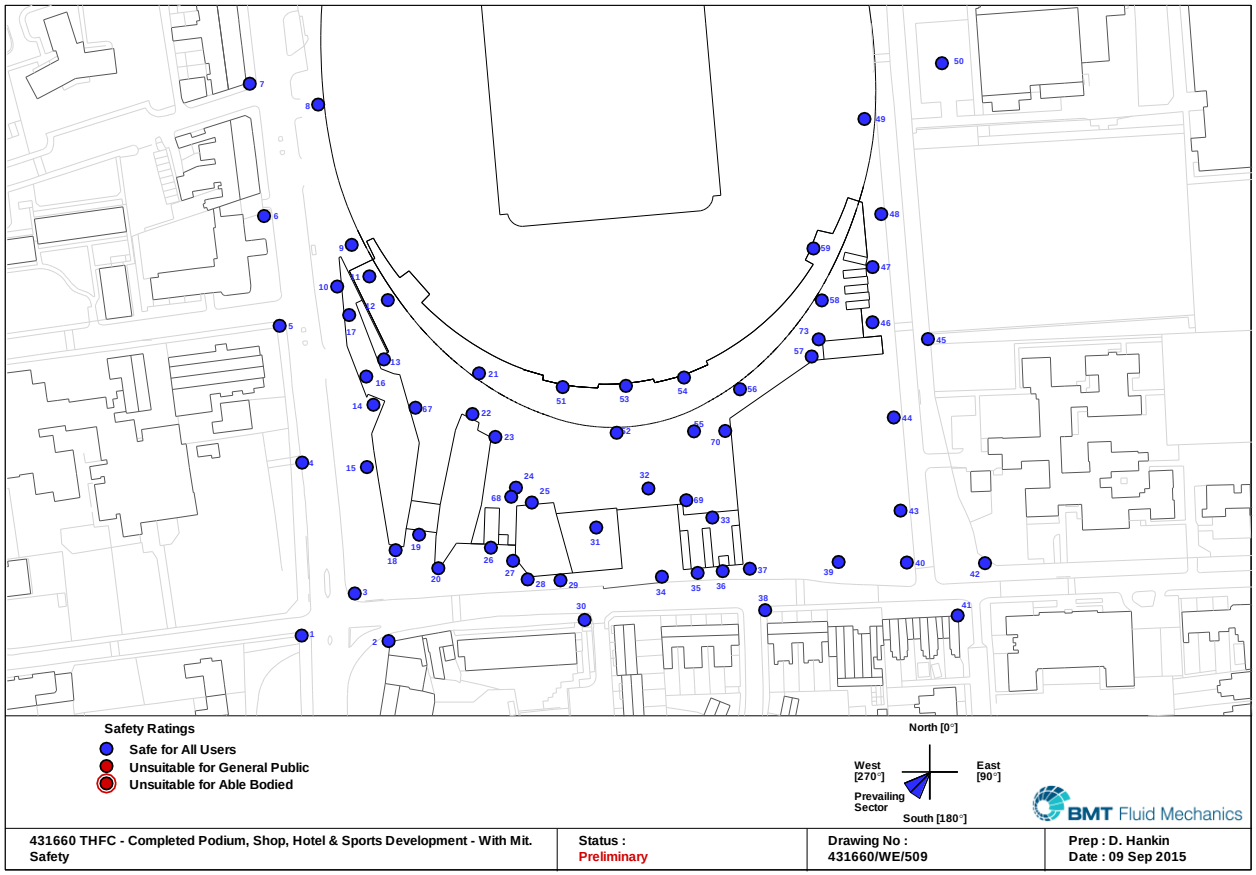


Figure D.1j: Annual safety ratings, the completed sports development, northern podium area, with soft landscaping and wind mitigation

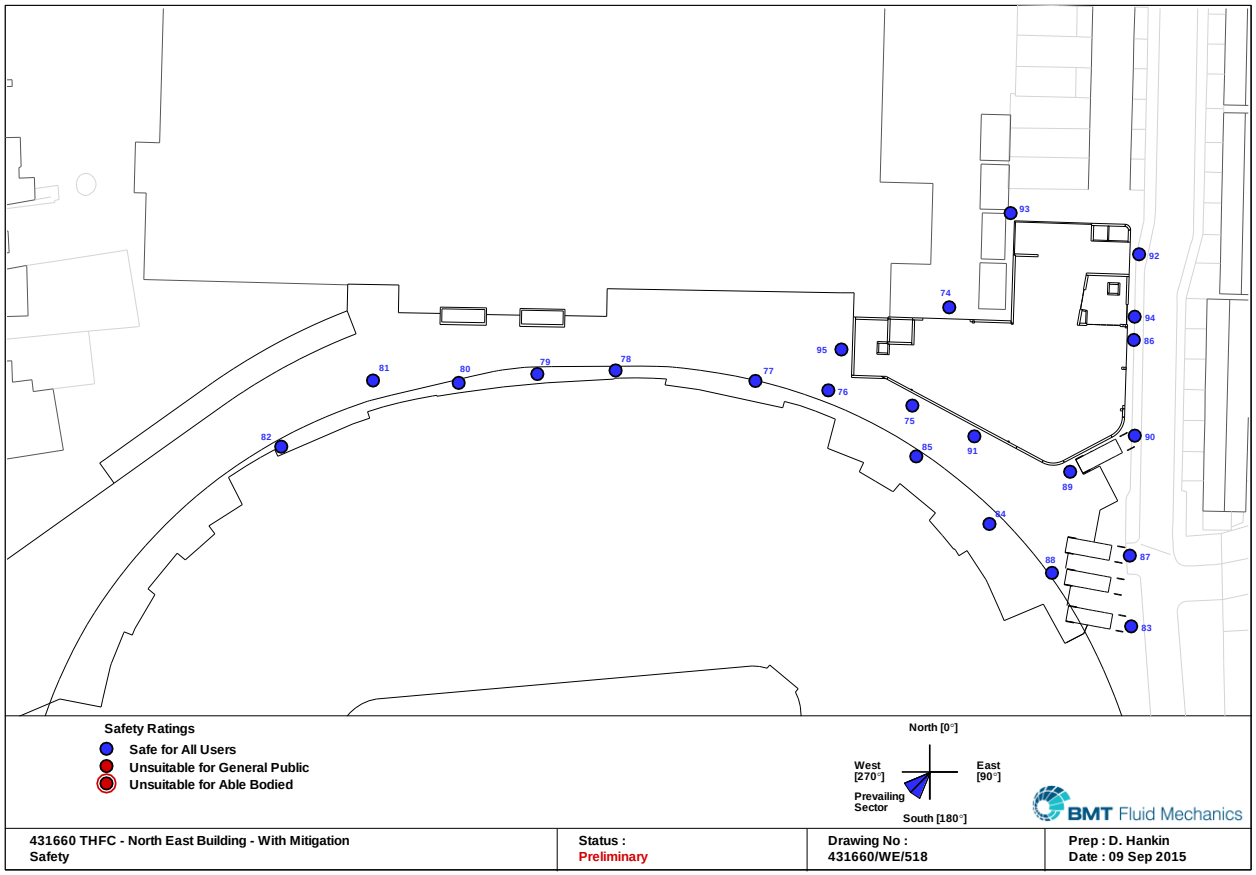


Figure D.1k: Annual safety ratings, the completed masterplan, southern podium area

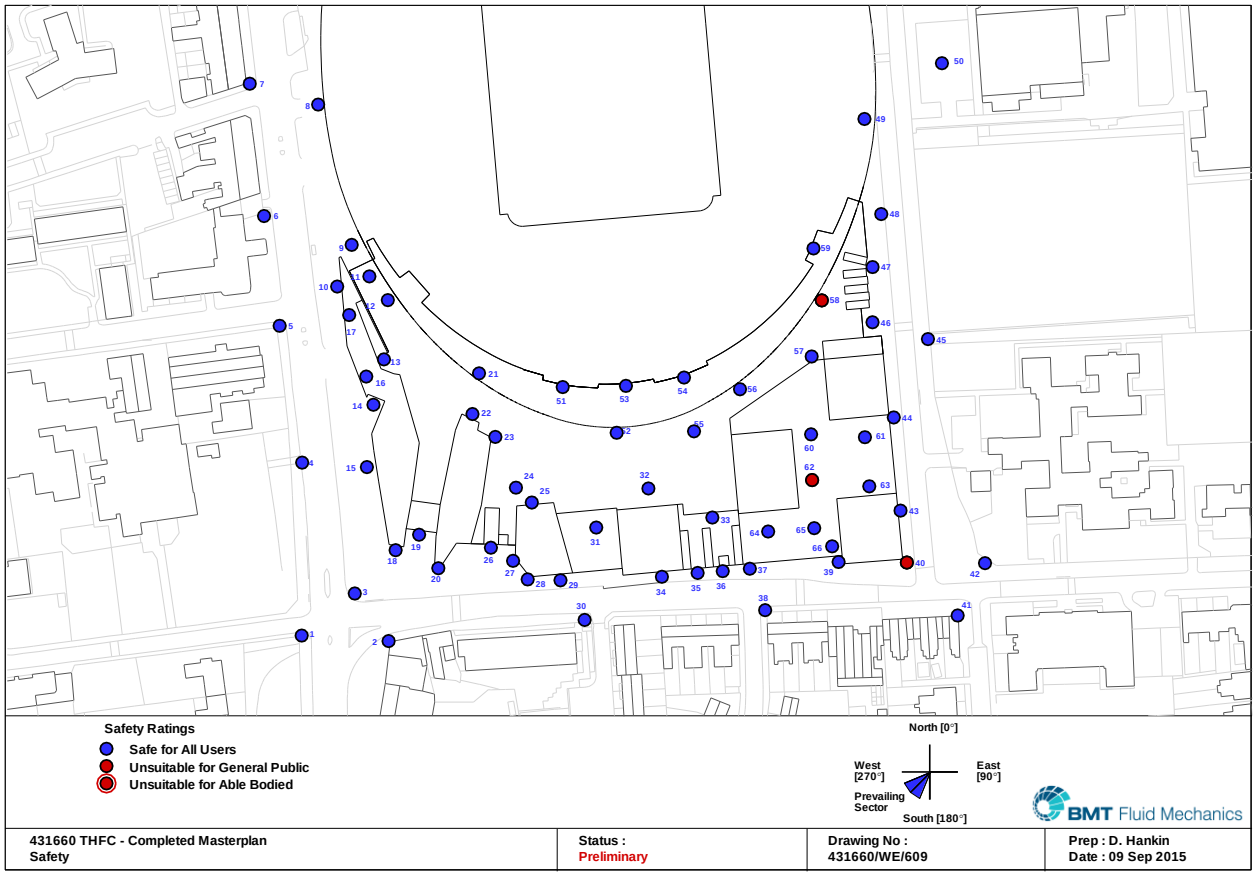


Figure D.1l: Annual safety ratings, the completed masterplan, southern podium area, with soft landscaping and wind mitigation

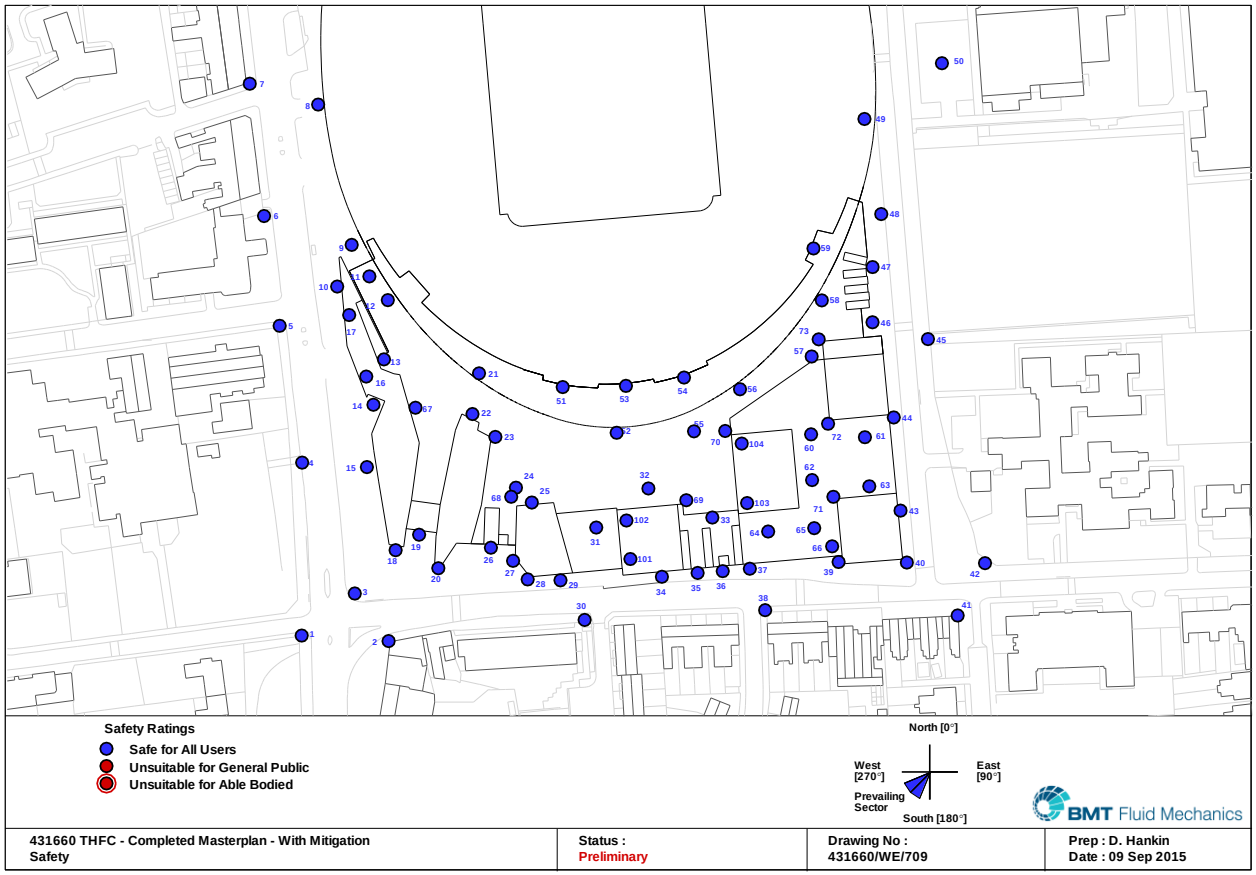


Figure D.2a: Summer comfort ratings, the opening day scenario, southern podium area

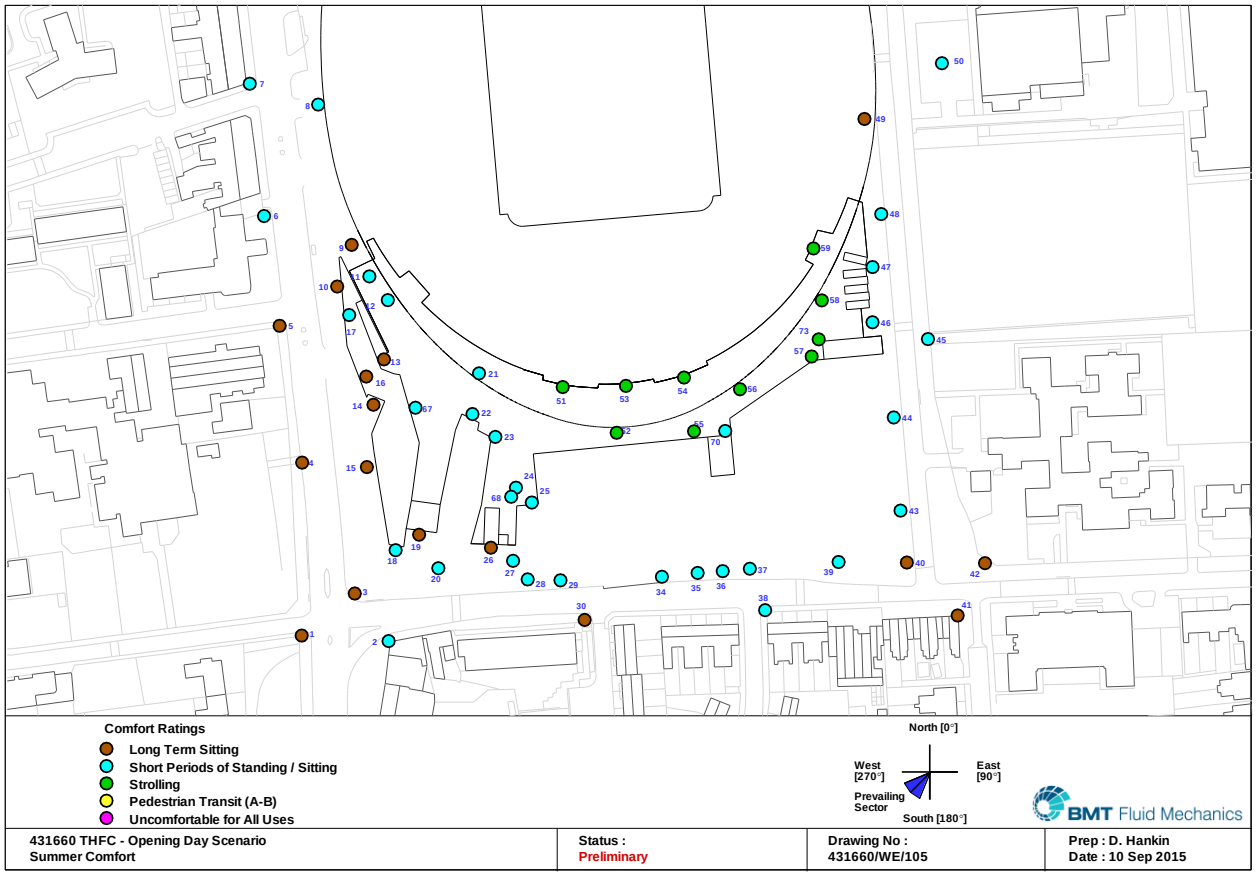


Figure D.2b: Summer comfort ratings, the opening day scenario, northern podium area

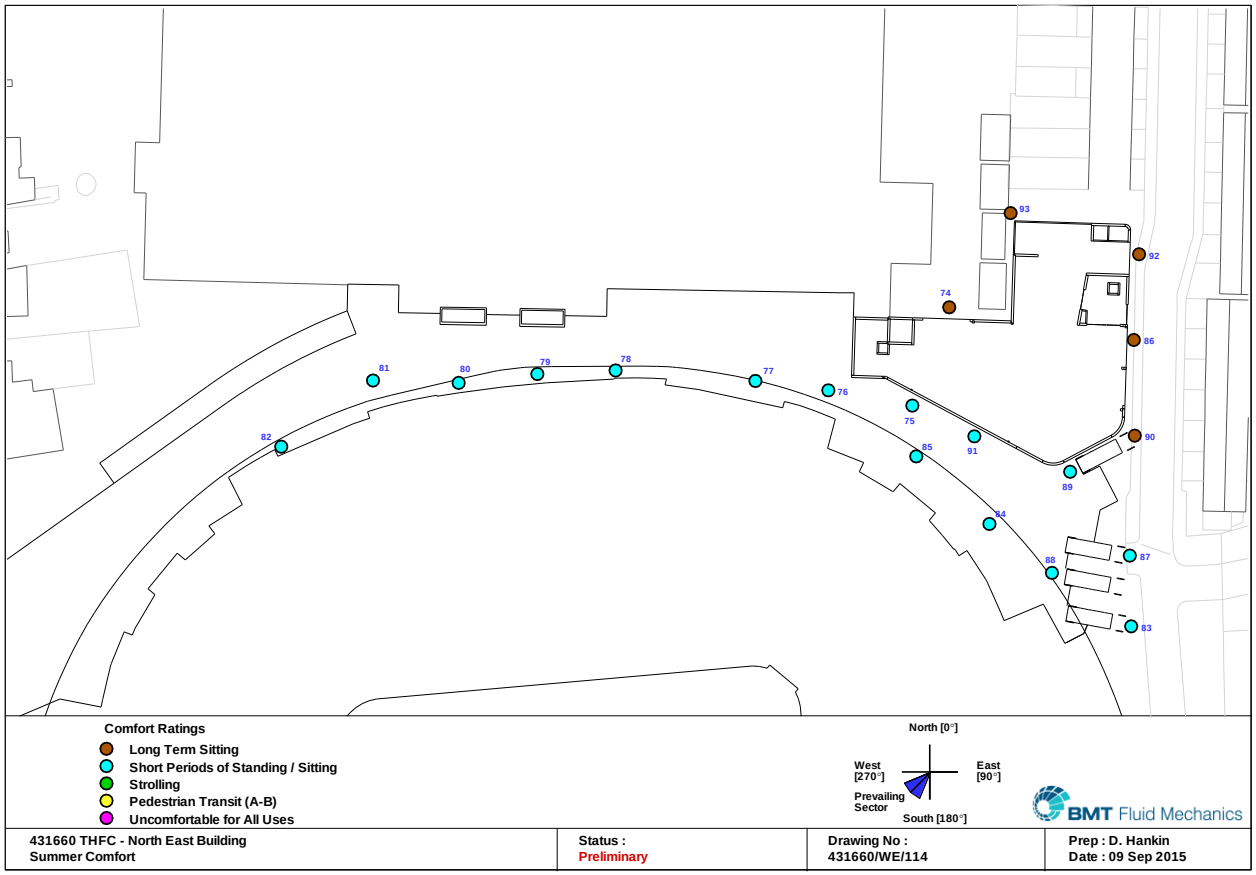


Figure D.2c: Summer comfort ratings, the opening day scenario, southern podium area, with soft landscaping and wind mitigation

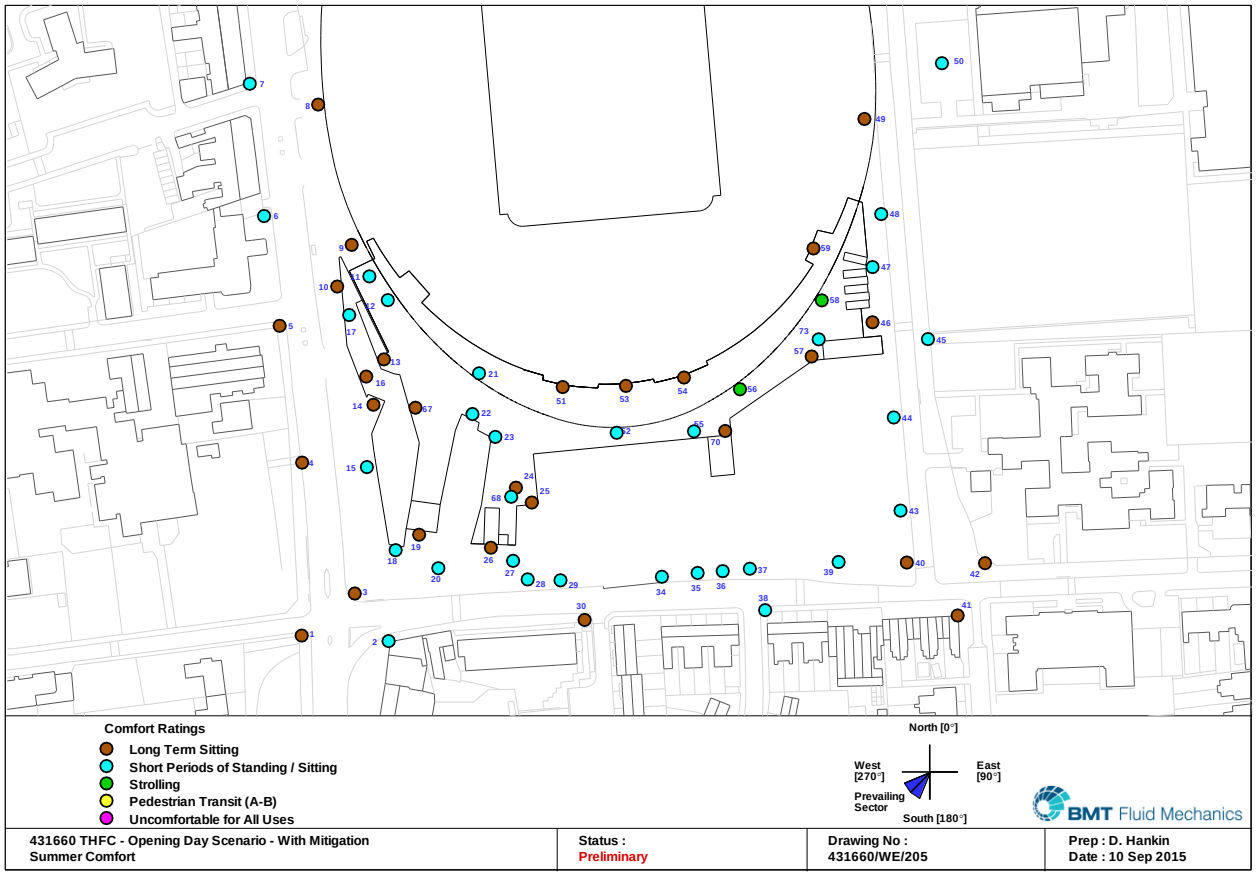


Figure D.2d: Summer comfort ratings, the opening day scenario, northern podium area, with soft landscaping and wind mitigation

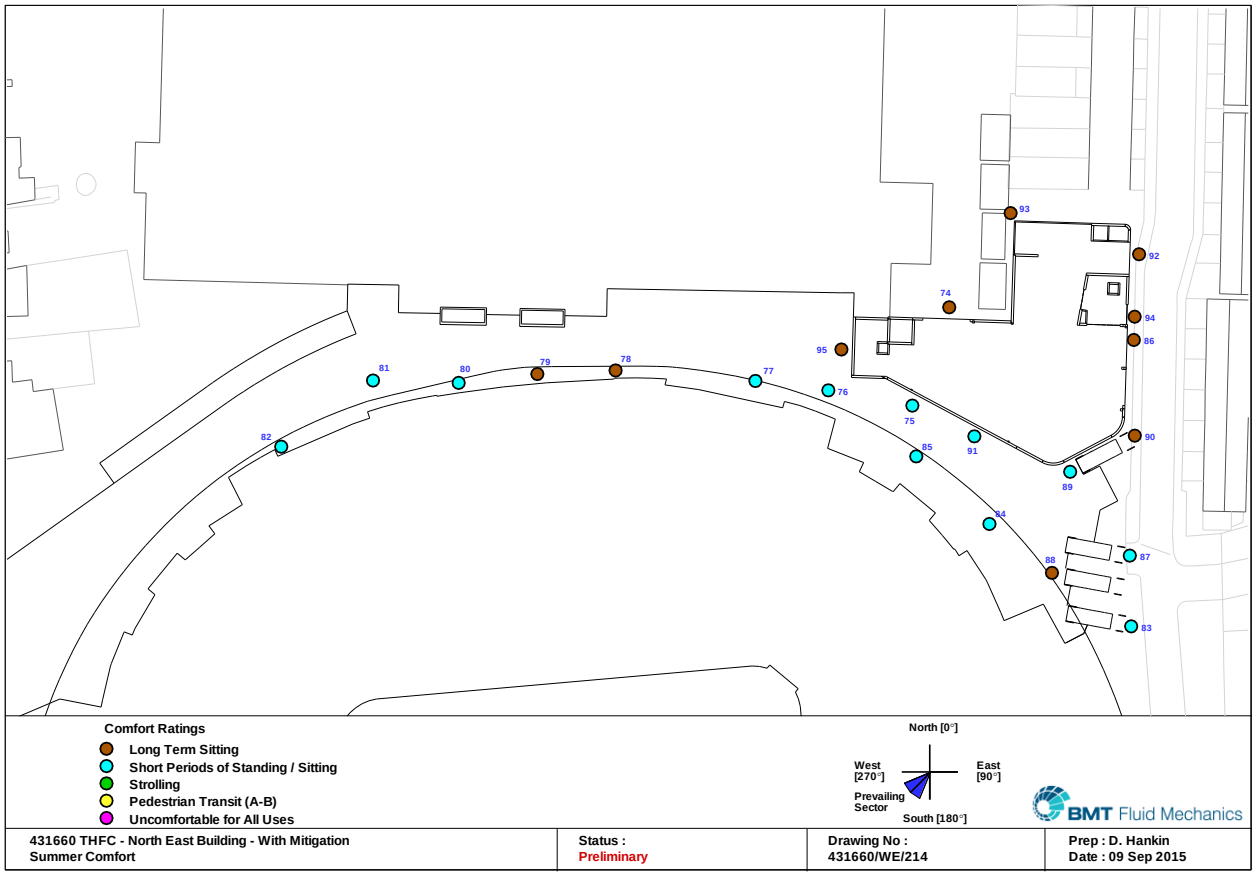


Figure D.2e: Summer comfort ratings, the completed podium, southern podium area, with soft landscaping and wind mitigation

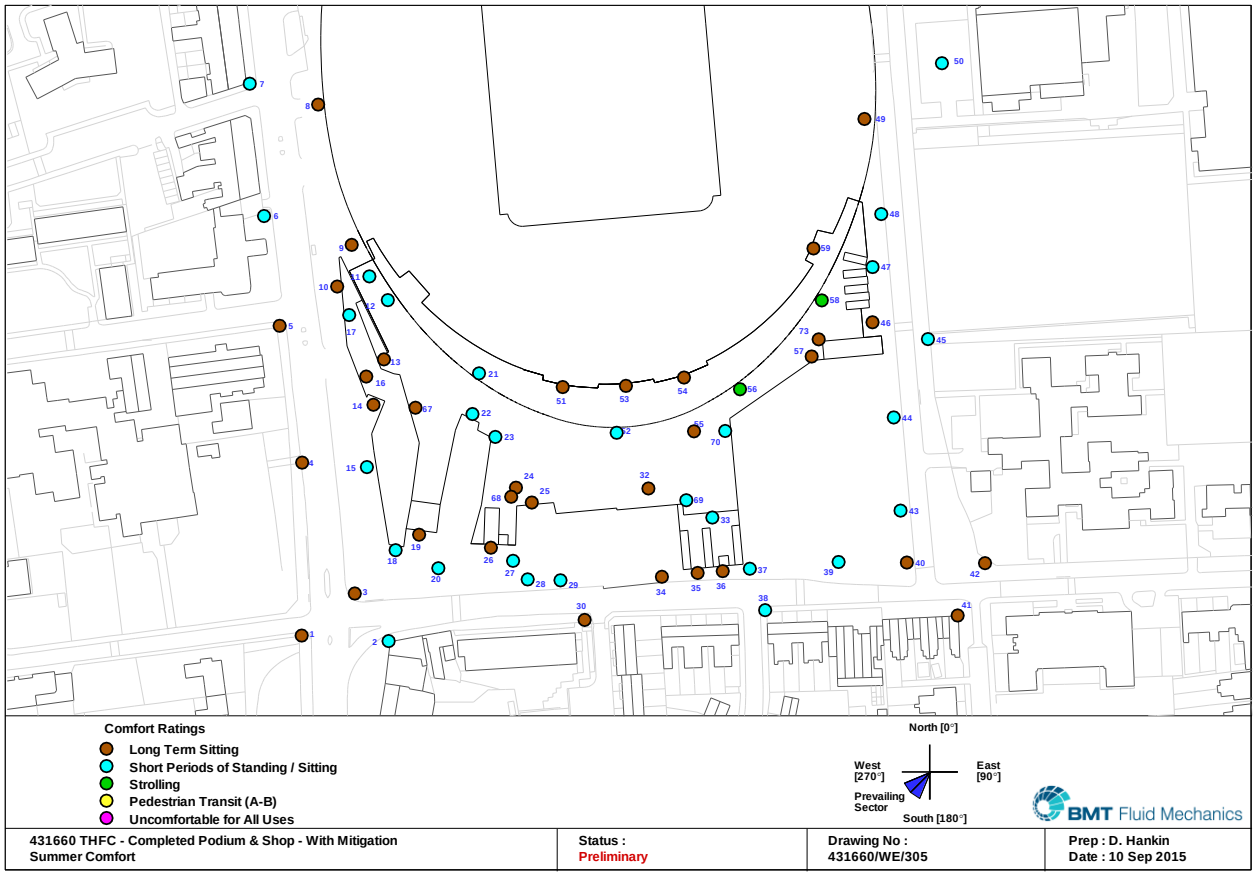


Figure D.2f: Summer comfort ratings, the completed podium, northern podium area, with soft landscaping and wind mitigation

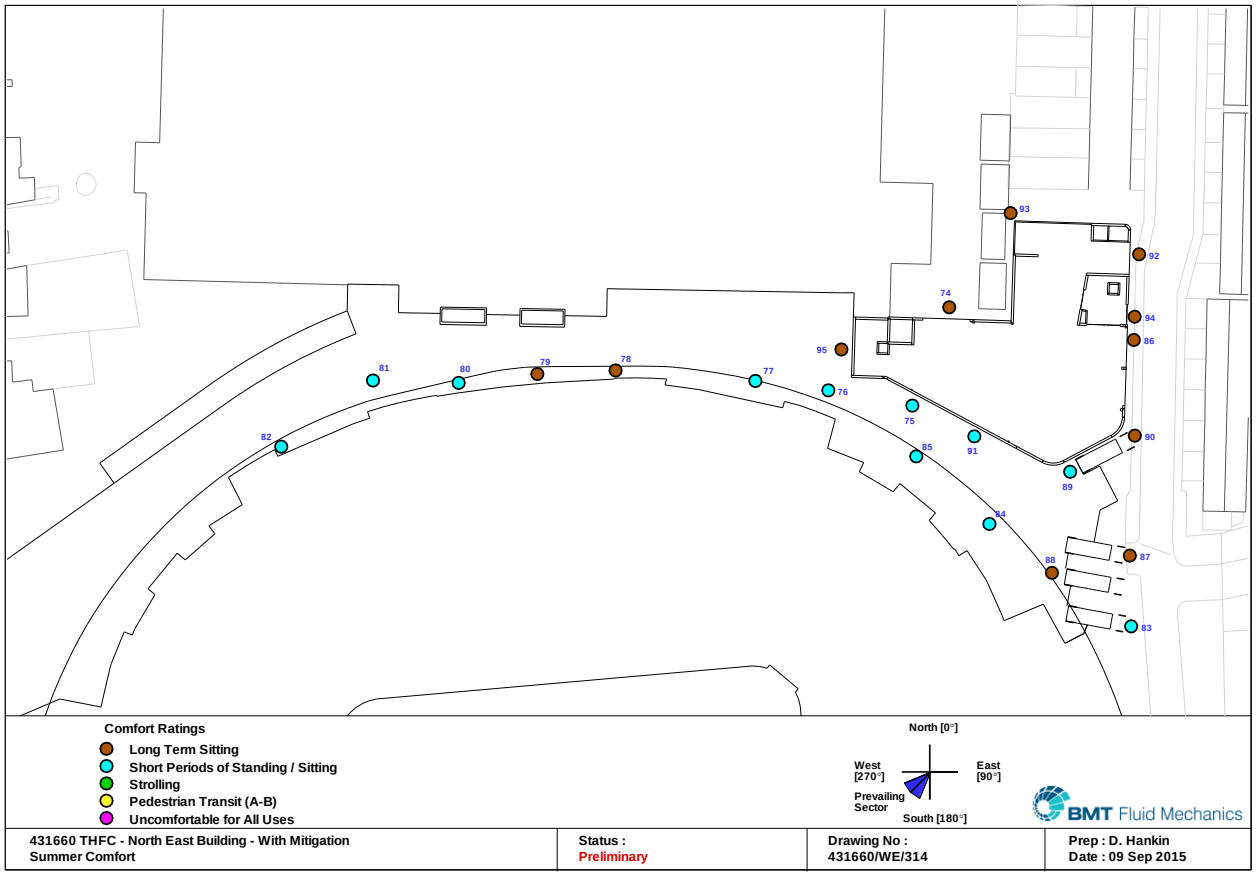


Figure D.2g: Summer comfort ratings, the completed hotel, southern podium area, with soft landscaping and wind mitigation

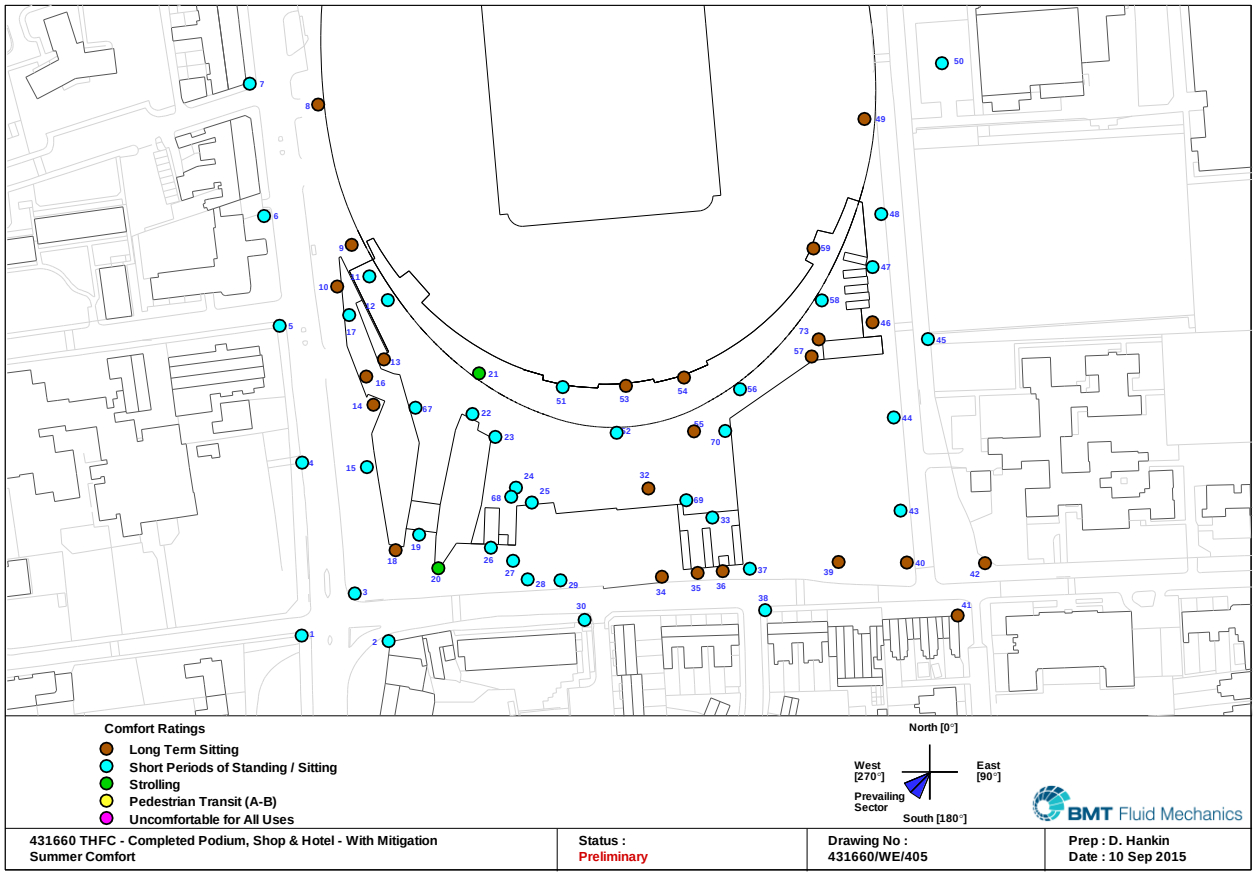


Figure D.2h: Summer comfort ratings, the completed hotel, northern podium area, with soft landscaping and wind mitigation

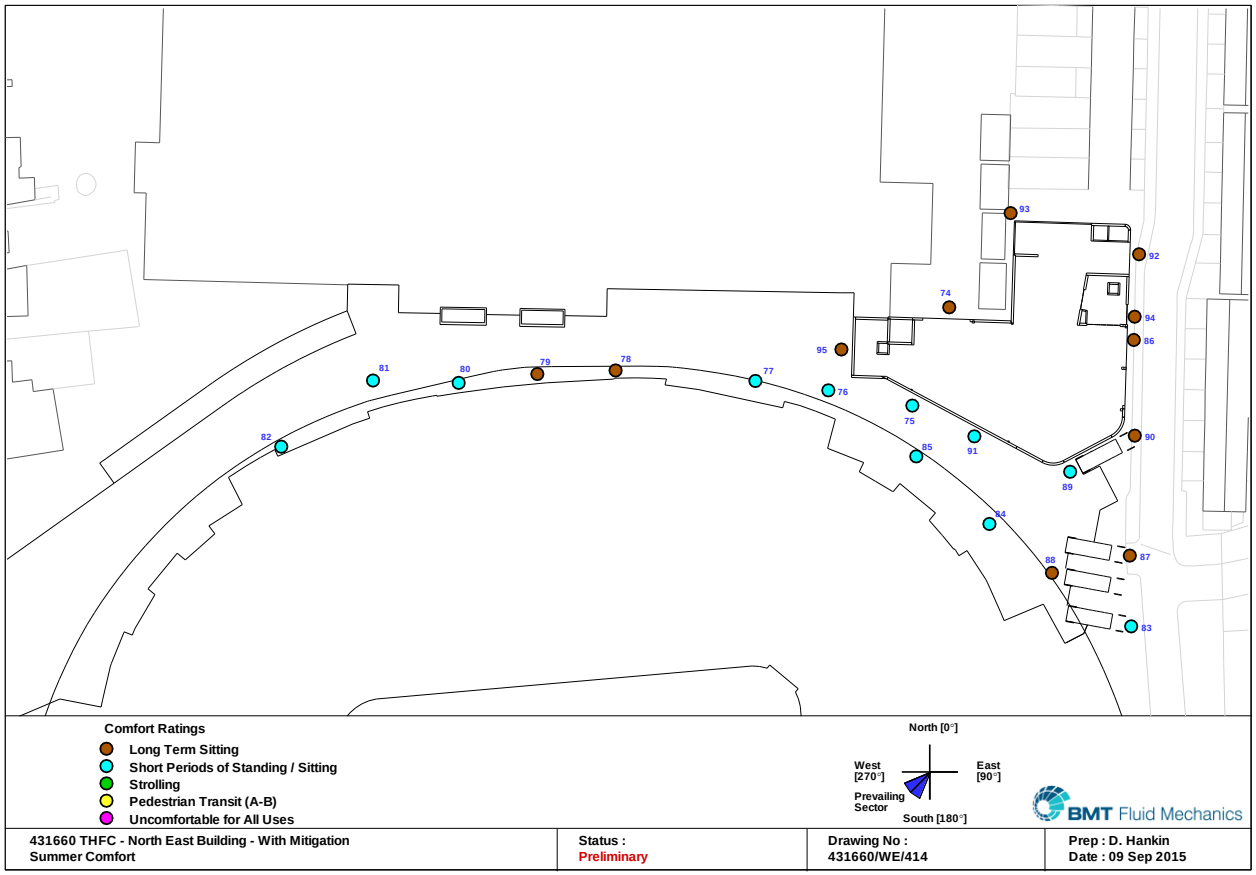


Figure D.2i: Summer comfort ratings, the completed sports development, southern podium area, with soft landscaping and wind mitigation

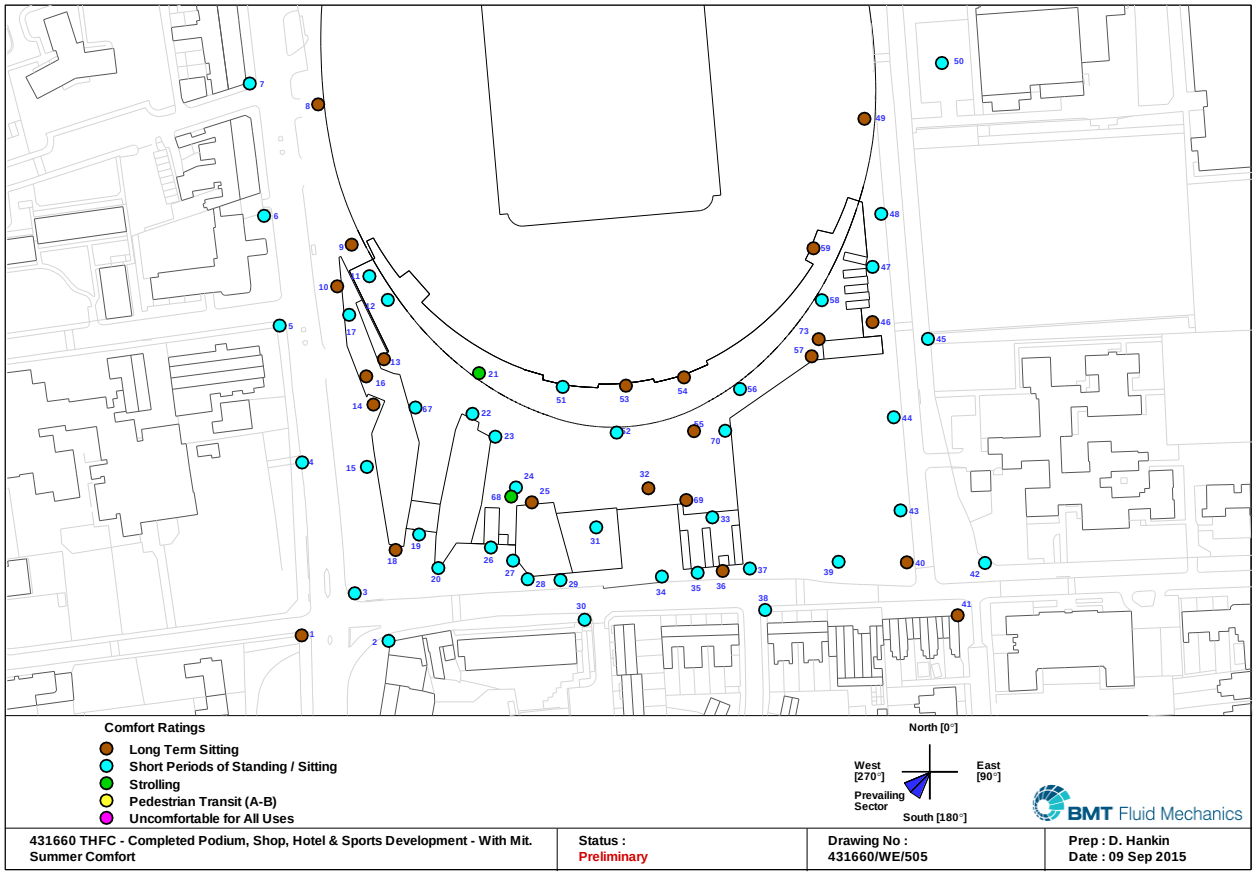


Figure D.2j: Summer comfort ratings, the completed sports development, northern podium area, with soft landscaping and wind mitigation

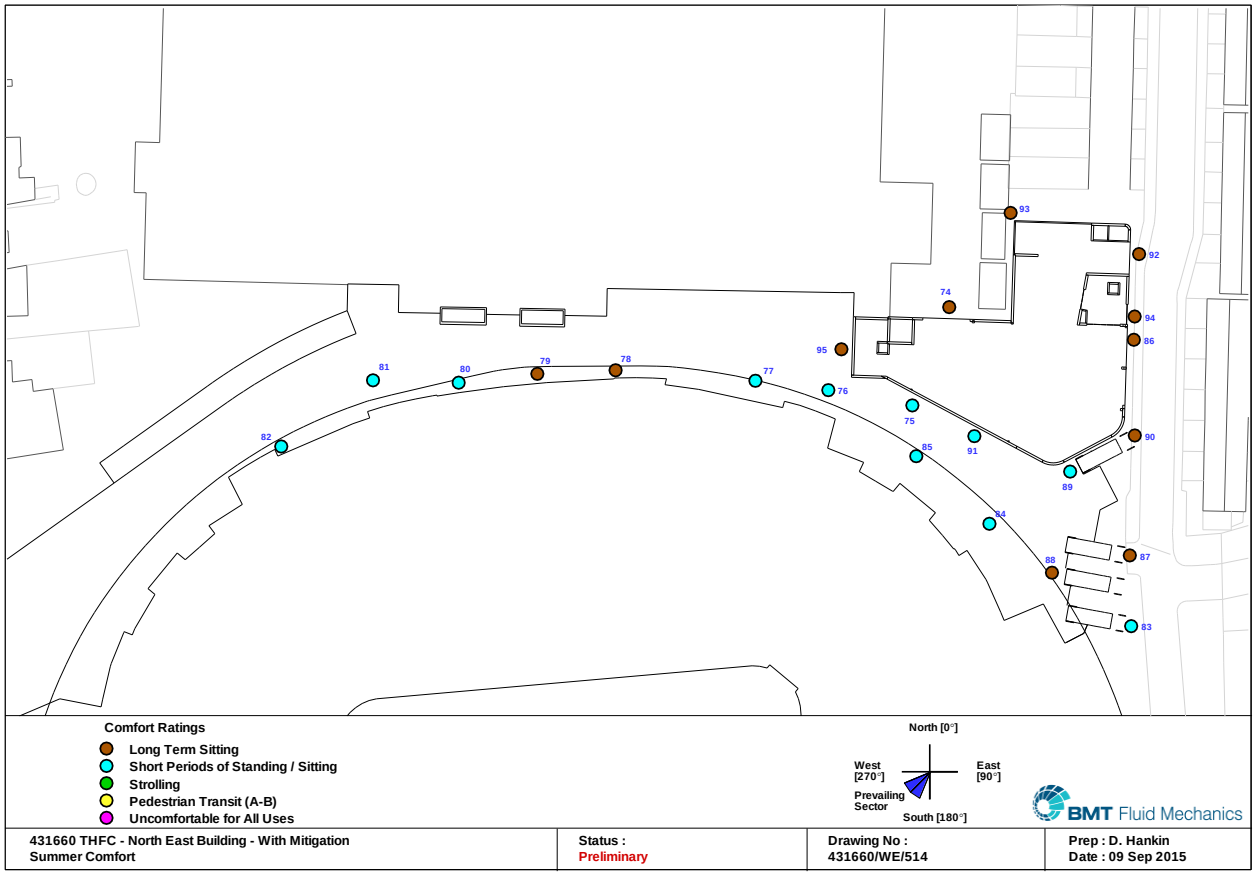


Figure D.2k: Summer comfort ratings, the completed masterplan, southern podium area

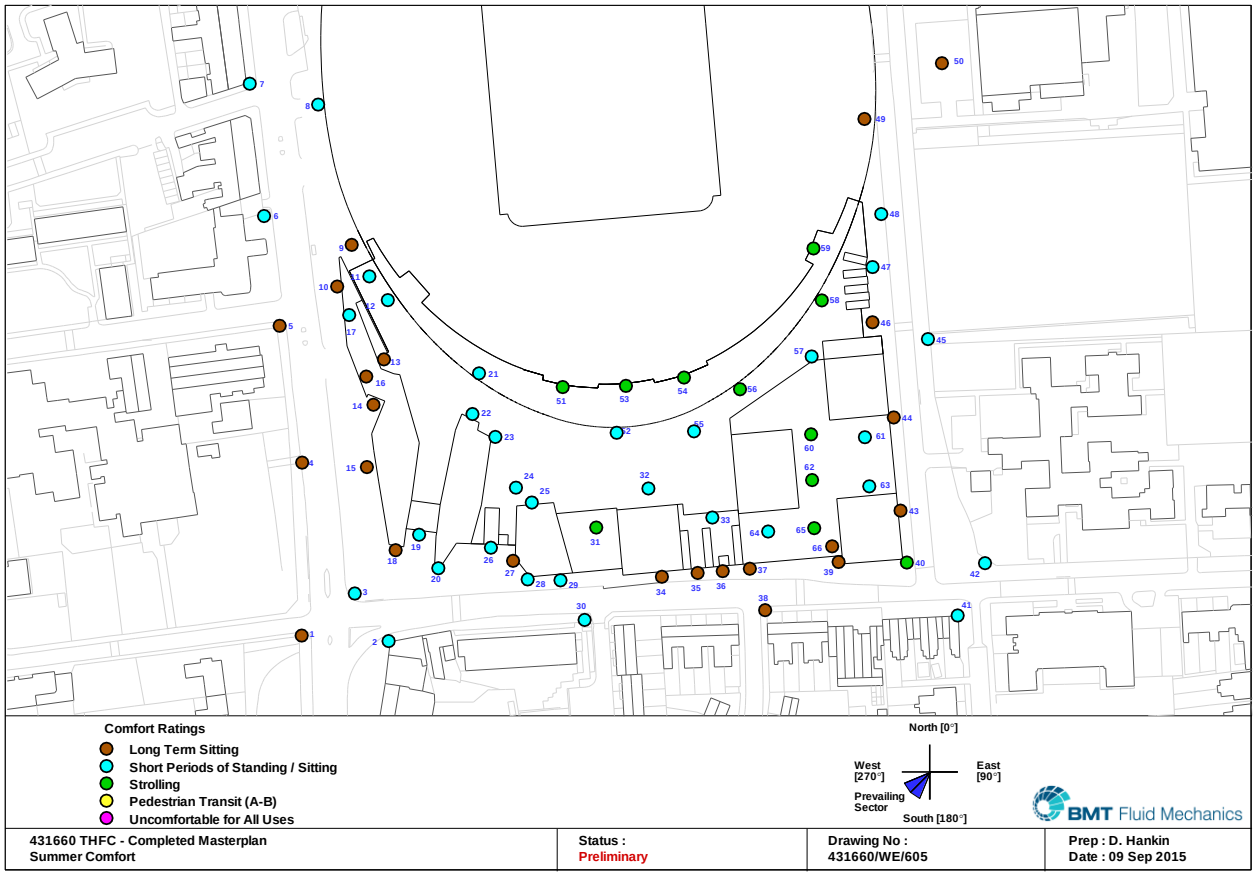


Figure D.2l: Summer comfort ratings, the completed masterplan, southern podium area, with soft landscaping and wind mitigation

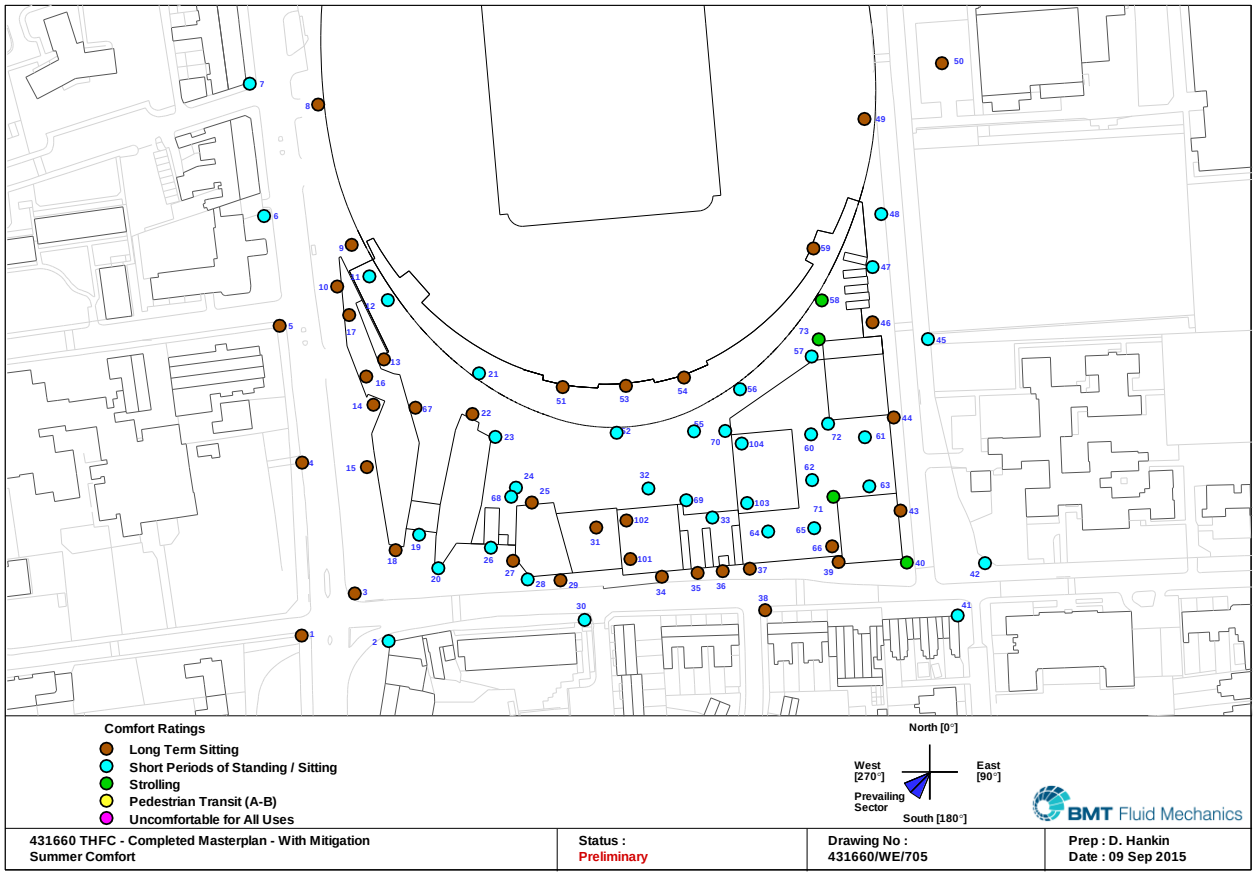


Figure D.3a: Worst seasonal comfort ratings, the opening day scenario, southern podium area

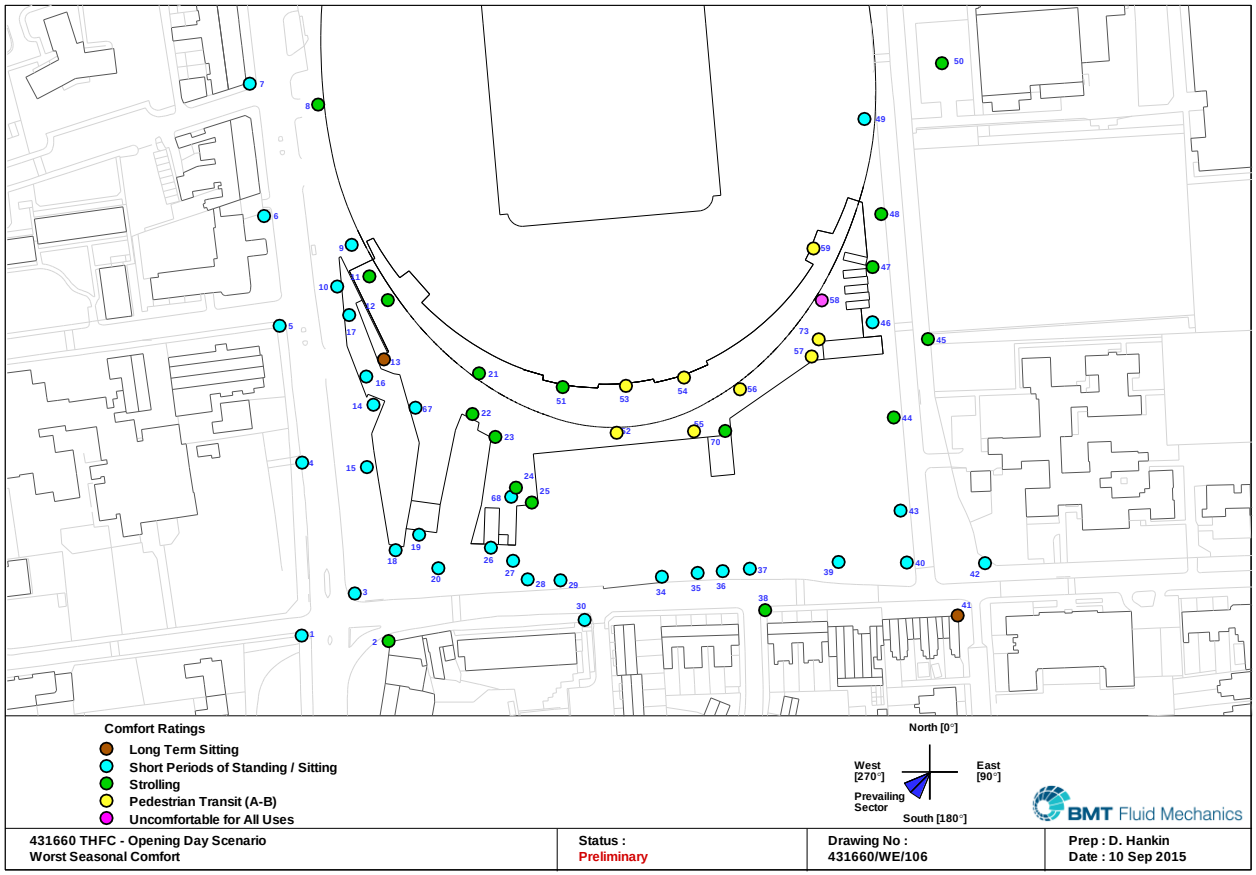


Figure D.3b: Worst seasonal comfort ratings, the opening day scenario, northern podium area

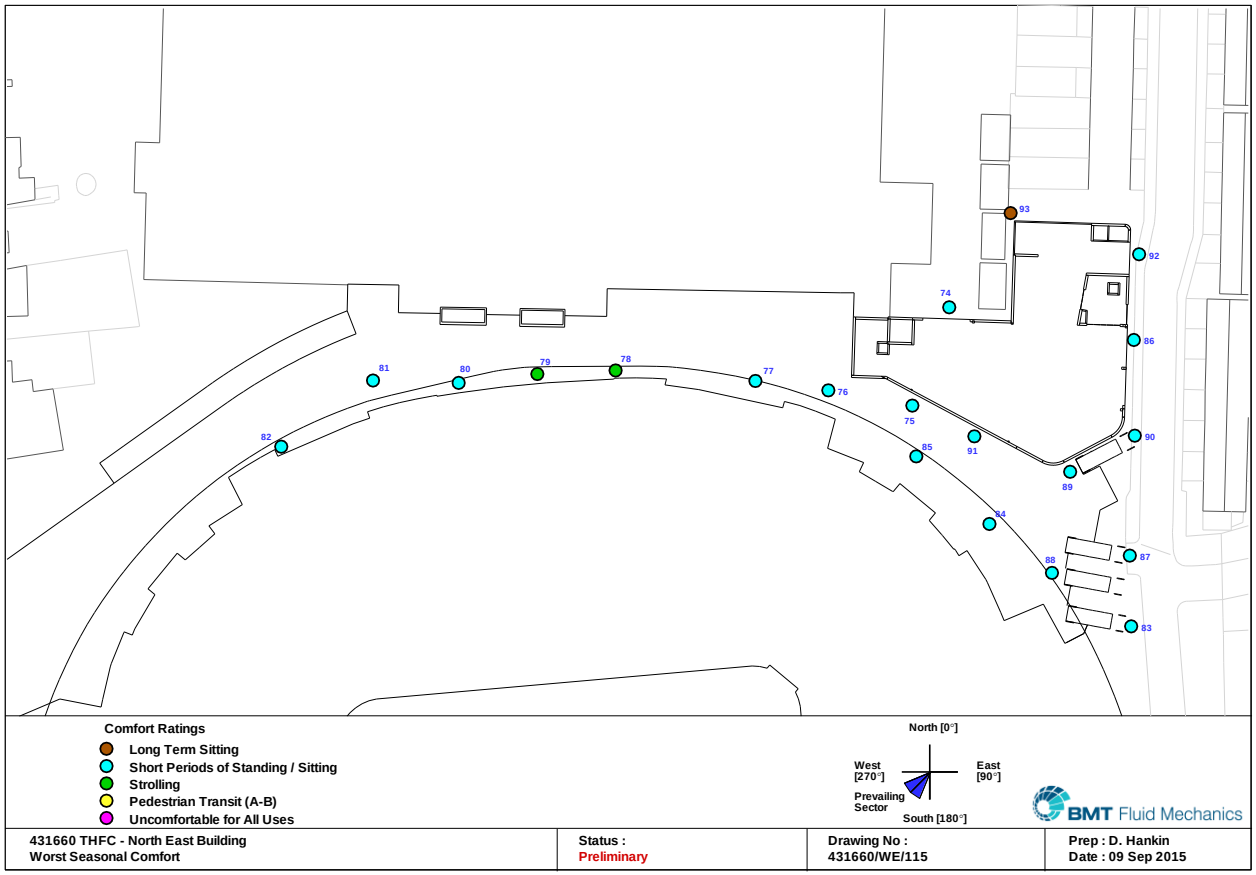


Figure D.3c: Worst seasonal comfort ratings, the opening day scenario, southern podium area, with soft landscaping and wind mitigation

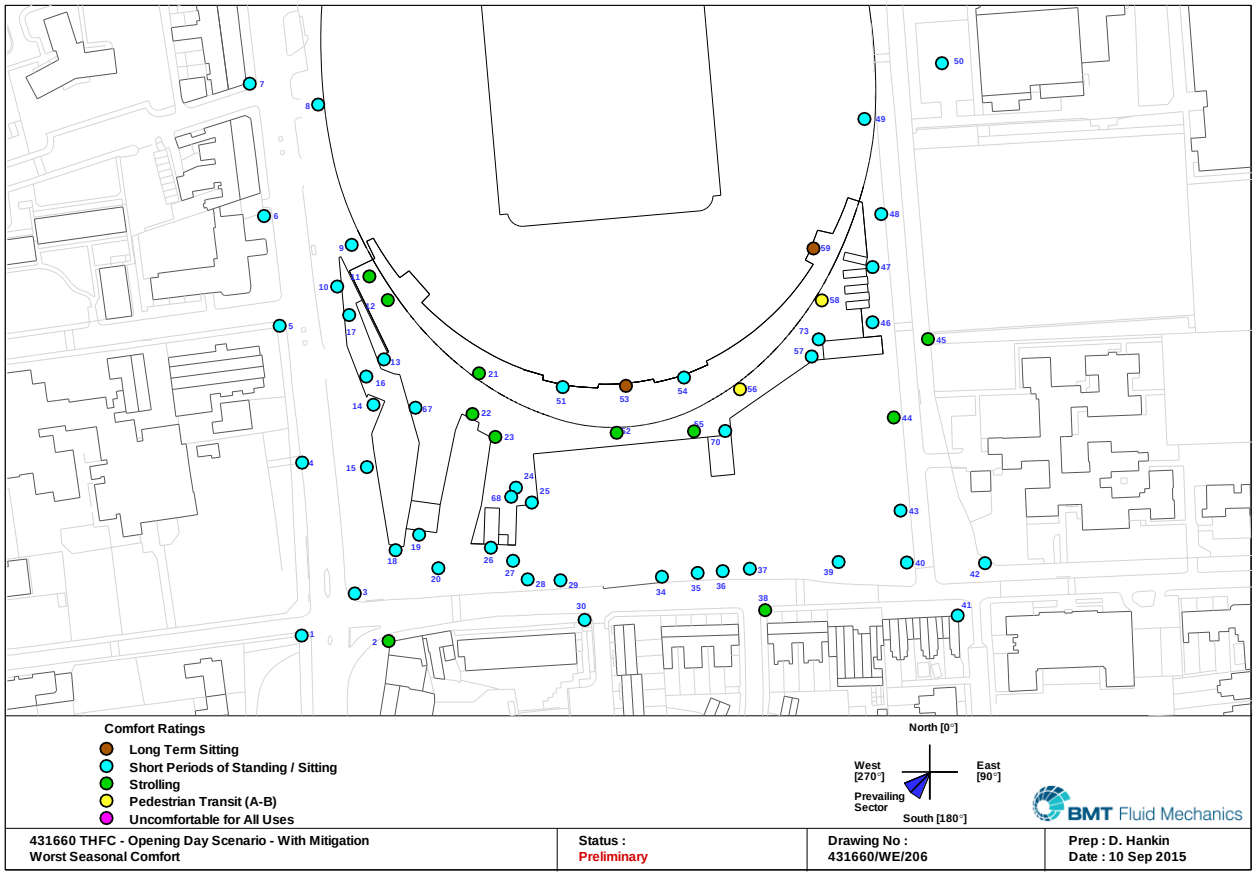


Figure D.3d: Worst seasonal comfort ratings, the opening day scenario, northern podium area, with soft landscaping and wind mitigation

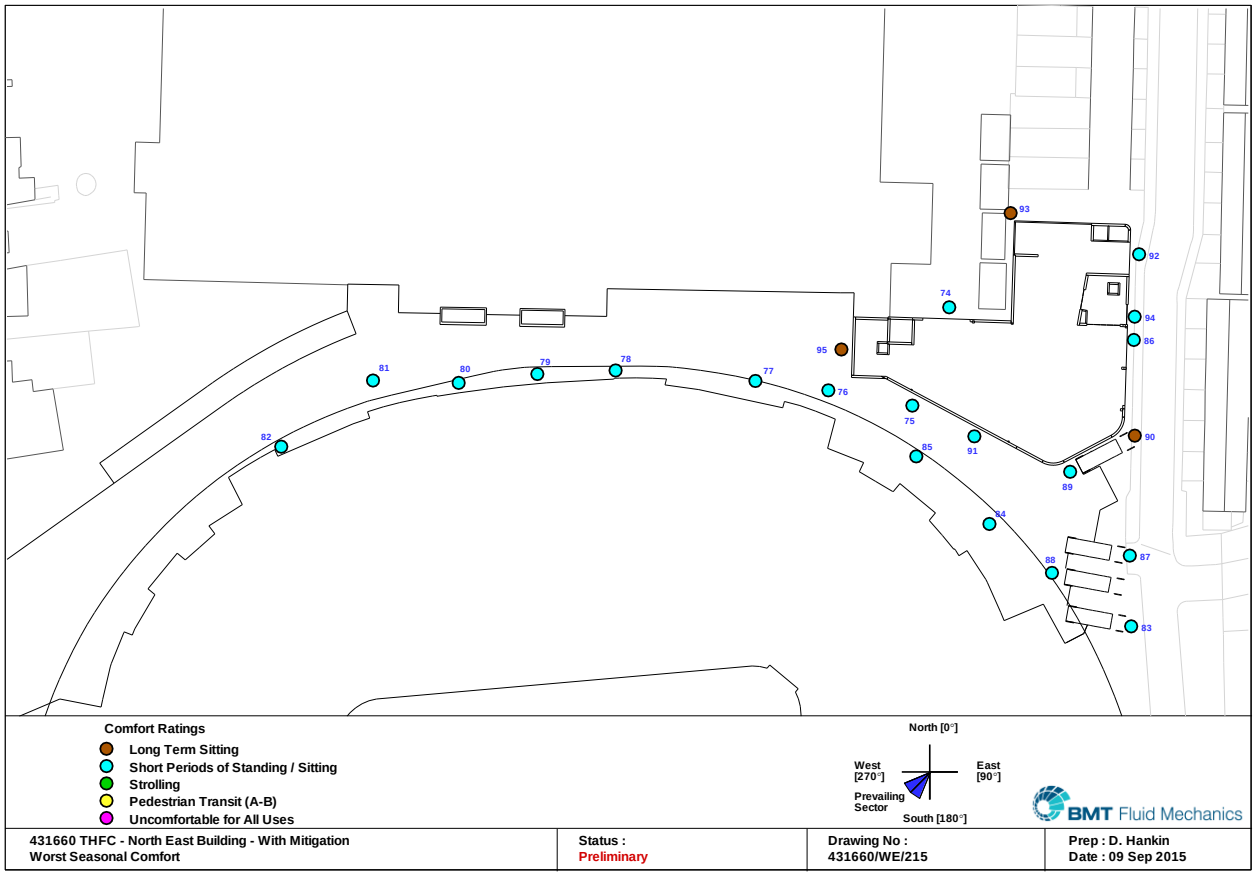


Figure D.3e: Worst seasonal comfort ratings, the completed podium, southern podium area, with soft landscaping and wind mitigation

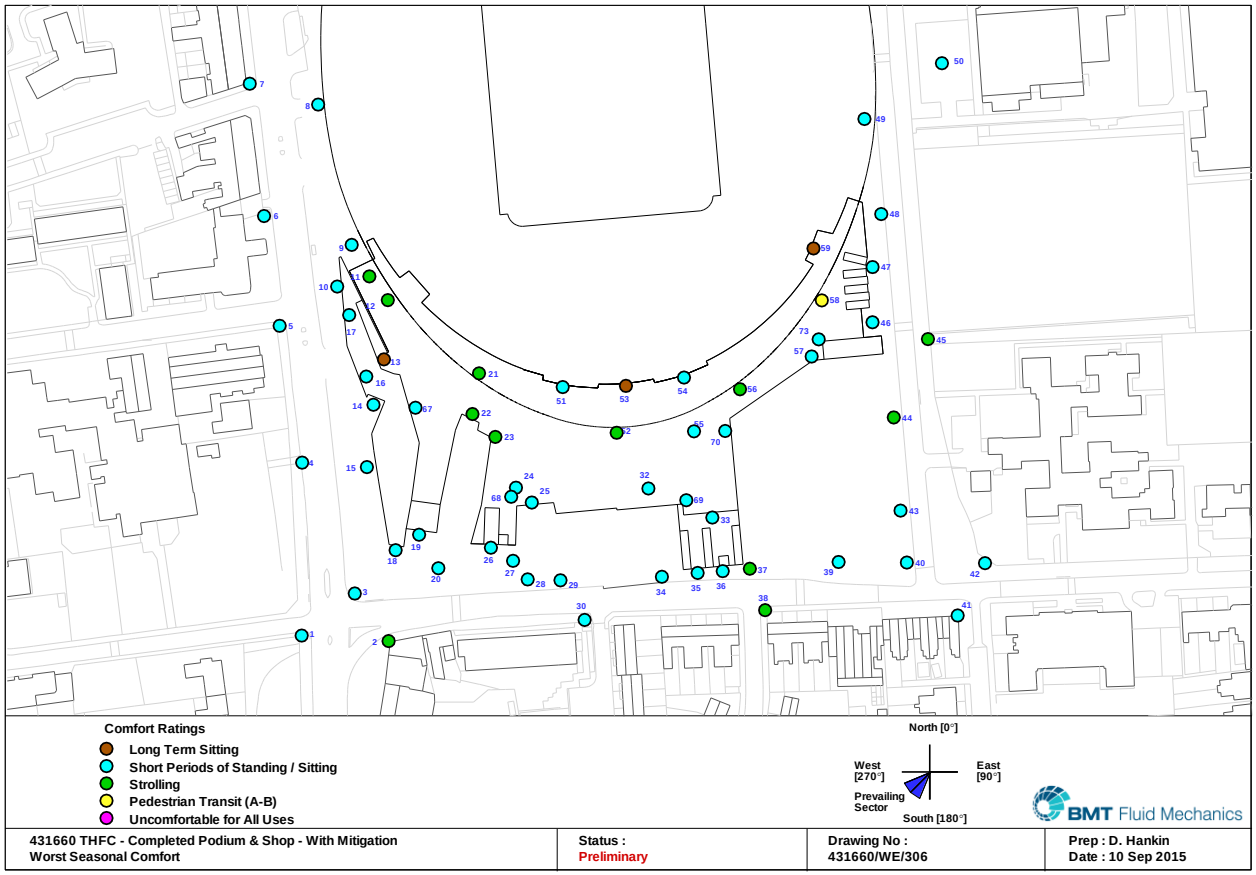


Figure D.3f: Worst seasonal comfort ratings, the completed podium, northern podium area, with soft landscaping and wind mitigation

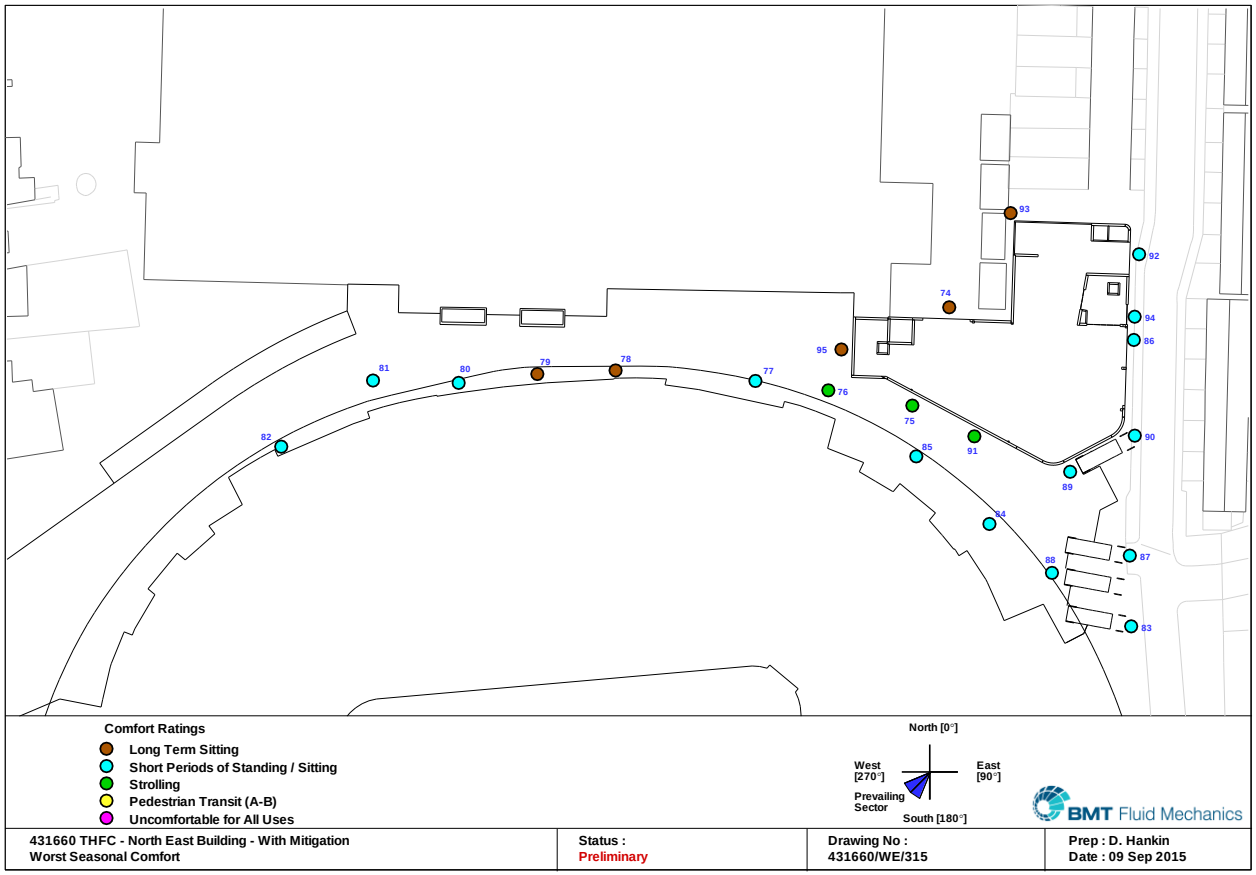


Figure D.3g: Worst seasonal comfort ratings, the completed hotel, southern podium area, with soft landscaping and wind mitigation

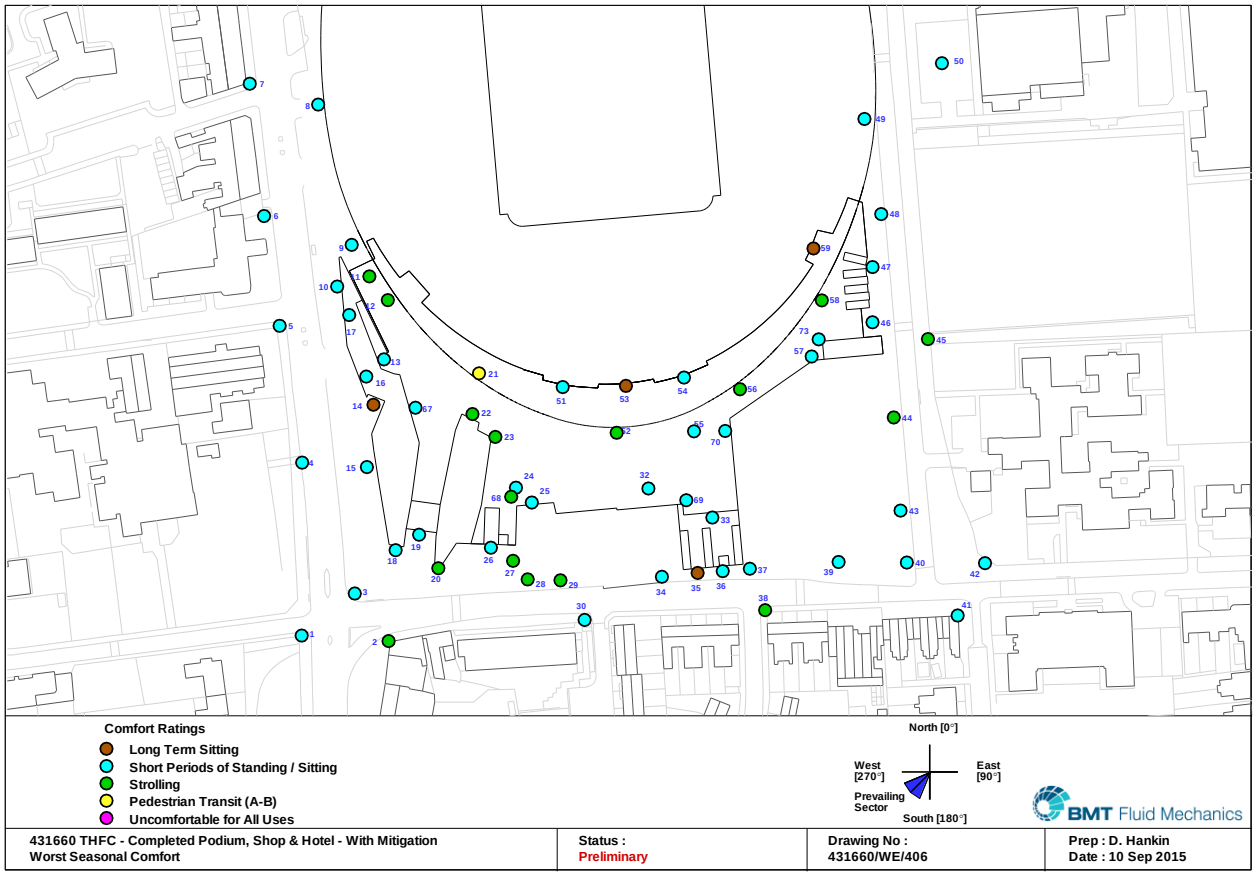


Figure D.3h: Worst seasonal comfort ratings, the completed hotel, northern podium area, with soft landscaping and wind mitigation

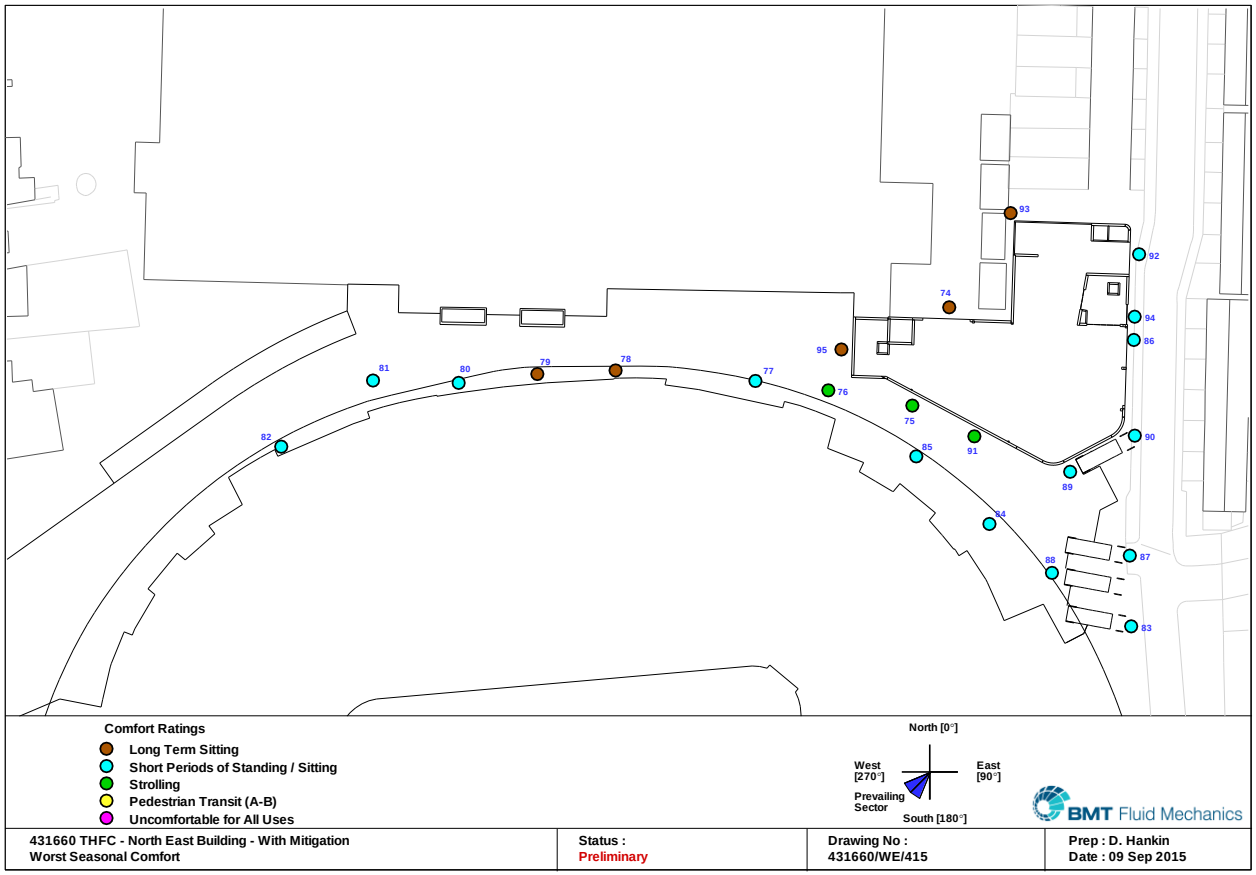


Figure D.3i: Worst seasonal comfort ratings, the completed sports development, southern podium area, with soft landscaping and wind mitigation

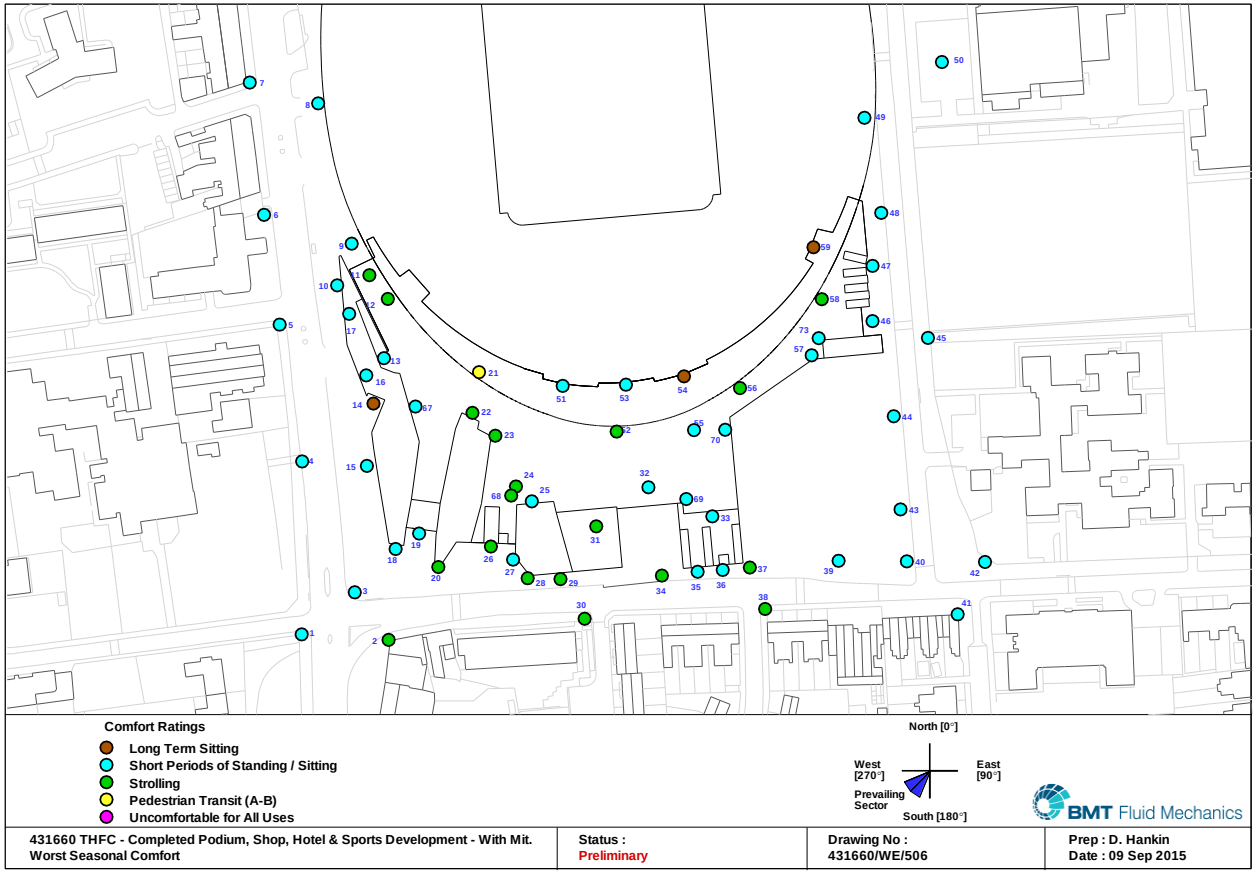


Figure D.3j: Worst seasonal comfort ratings, the completed sports development, northern podium area, with soft landscaping and wind mitigation

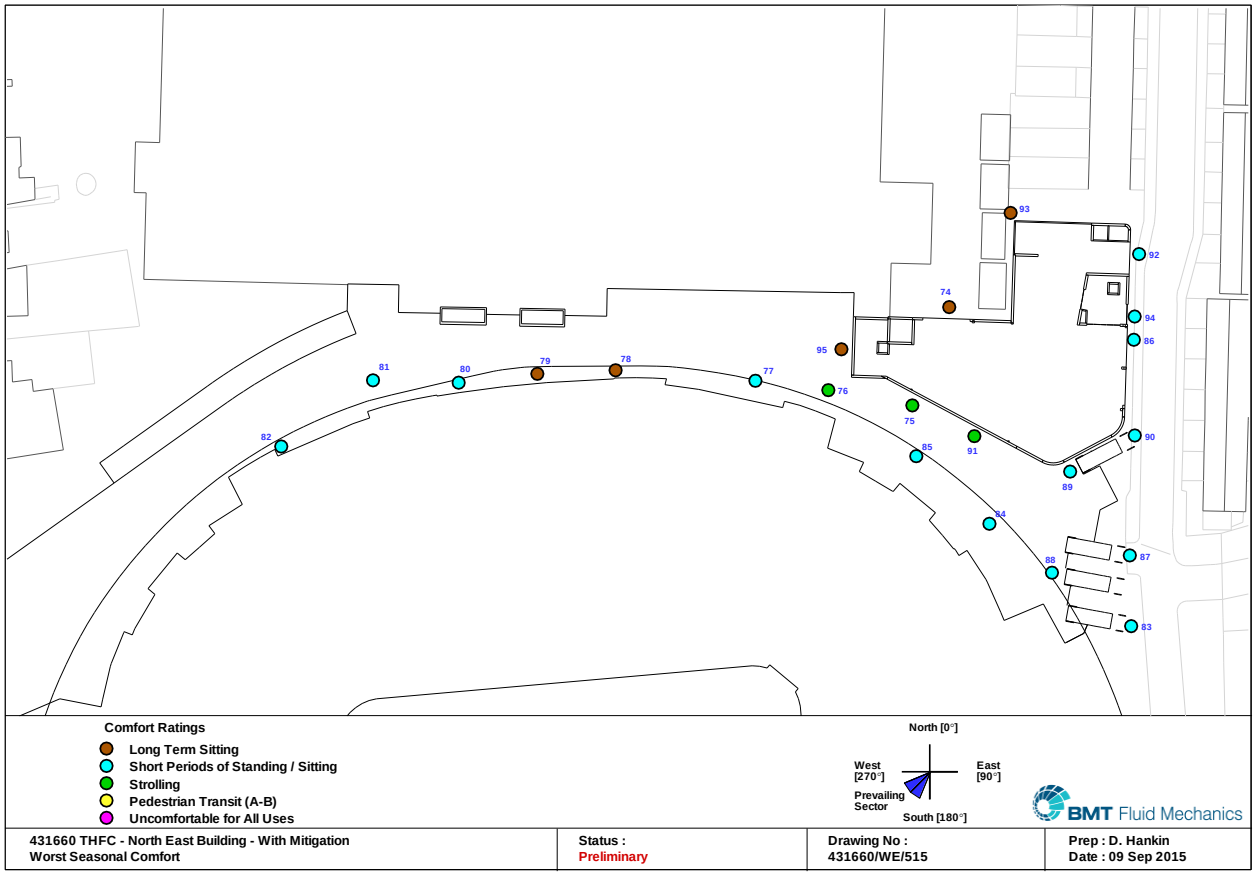


Figure D.3k: Worst seasonal comfort ratings, the completed masterplan, southern podium area

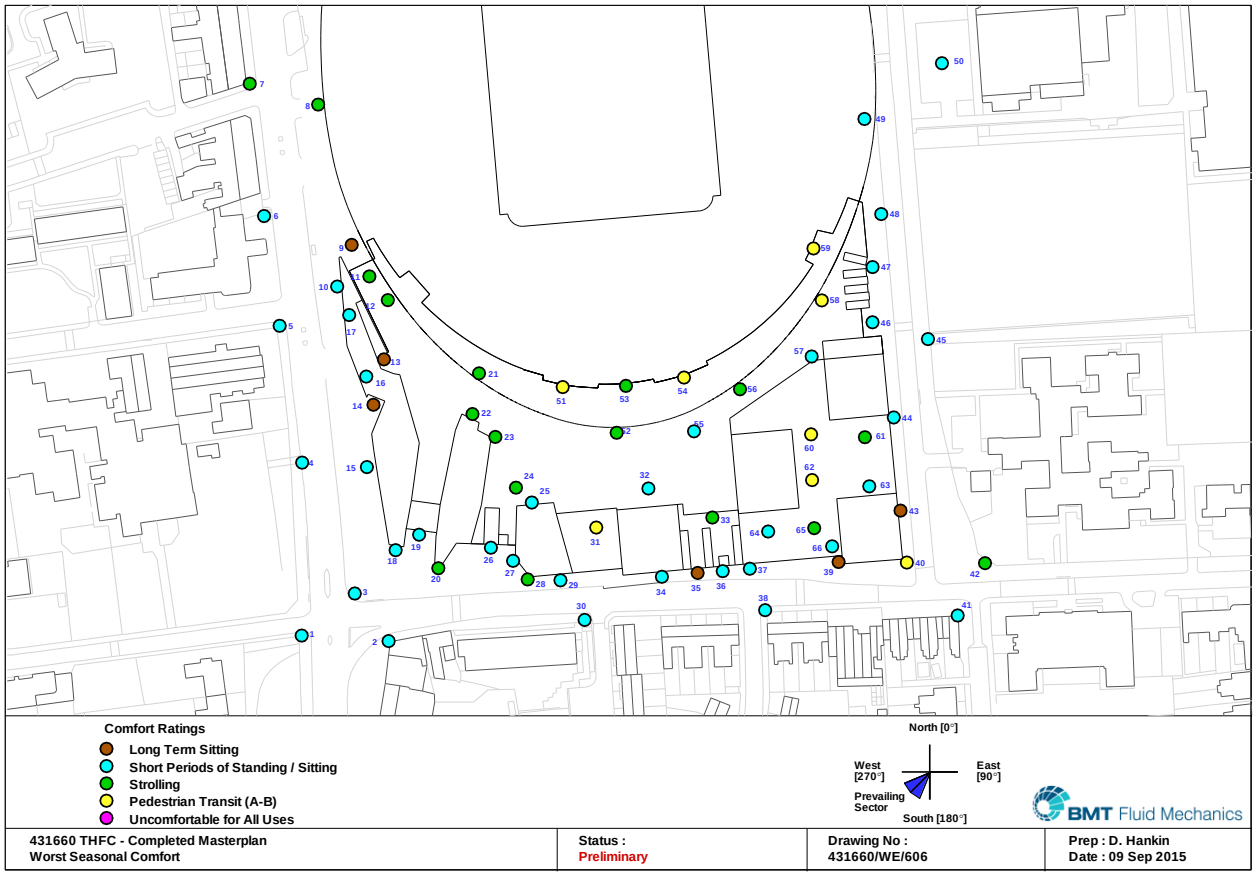
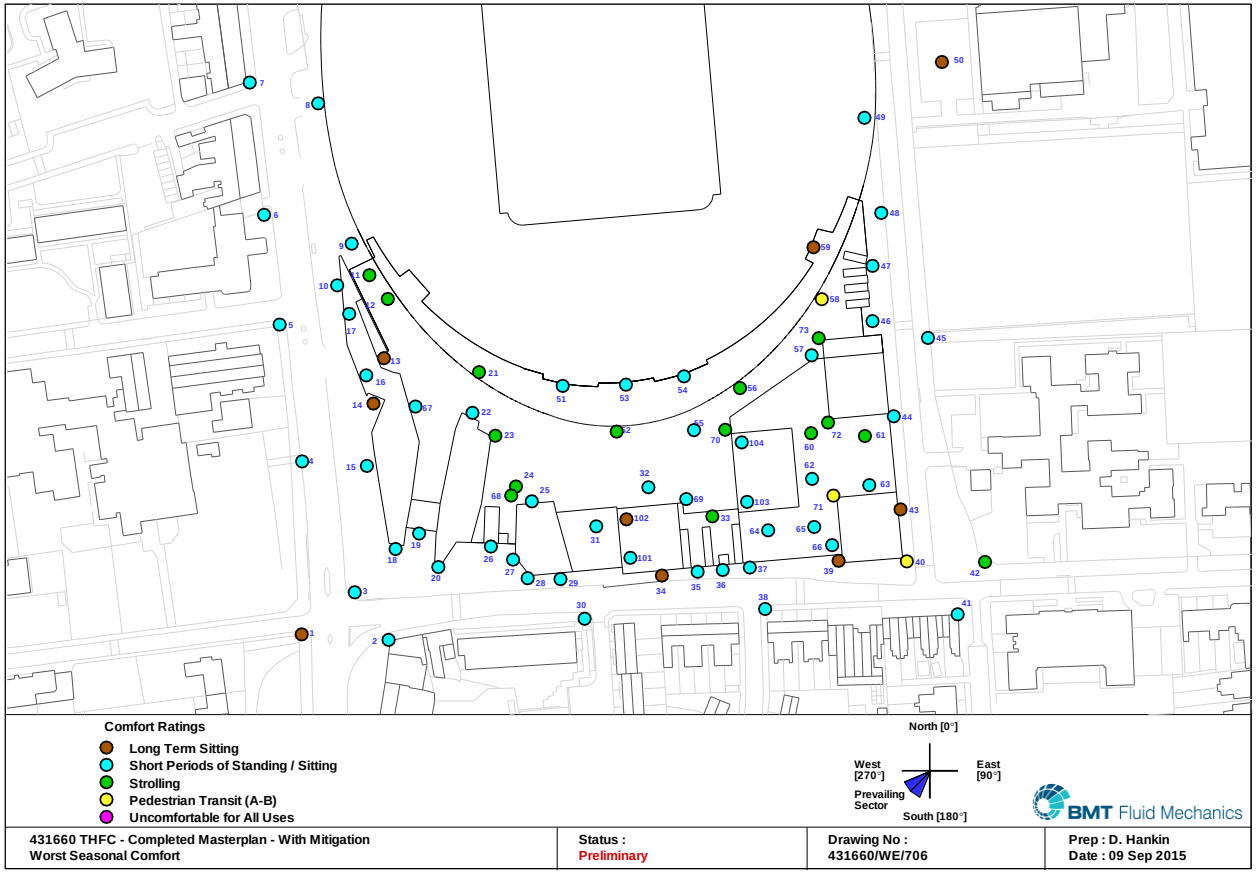



Figure D.3l: Worst seasonal comfort ratings, the completed masterplan, southern podium area, with soft landscaping and wind mitigation